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SOME EXPERIENCES AND LESSONS LEARNED IN SPINNING AEROPLANES.

By JAMES B. TAYLOR, Jun., A.F.R.Ae.S., M.I.Ae.S., M.Amer.S.Mech.E.

The author's experience in flying dates from before the war and includes a good many years as a naval test pilot, over 5,000 hours of actual flying time in the air in some 360 different types of aeroplanes, ranging from purely experimental to large modern passenger transports and the latest single-seater fighters, and the interest created by some of his experiences has prompted him to attempt some consideration of the complex problem of spinning.

The phrase " tail spin " was probably adopted by reason of the fact that when an aeroplane is in this manœuvre, it appears, from the ground, as though the nose were pointed straight down and the tail was describing a circle, whereas a spin is a complicated manœuvre and the nose is actually travelling in a helical flight path, the radius of this helix being relatively small.

The spin may be produced by stalling the aeroplane when in free flight. The wing, when stalled at a high angle of attack becomes unstable around its longitudinal axis and tends to autorotate. This, in combination with a yawing moment of the tail, causes the spin. The result is a combined yaw, roll, pitch and sideslip.

If the elevator control is held all the way back, and the rudder is held hard over, the aeroplane remains completely stalled at the high angle and the spin continues. If, when the rudder is reversed and the elevator control is pushed forward, the spin stops in a turn or a turn and a half, the aeroplane is generally considered satisfactory as to its spinning characteristics. This does not always happen, as the tail surfaces may be blanketed by the wings, or in some instances, the tail surfaces (particularly the vertical fin and rudder) are not large enough. Sometimes the spin tends to flatten out, in which case the nose is not so steeply inclined, the radius of the helix path is smaller, and the speed of rotation is higher. In other cases, the spin does not flatten out but tends to become uncontrollable.*

In general, there are two types of spins, controlled and uncontrollable and the latter may be in several different forms, some of which are completely flat, in which the aeroplane revolves very rapidly, without much loss of altitude, and the others in which the nose is straight down, but the controls are ineffective.

A great deal of research work has already been done in connection with spinning and the mechanics of the art of spinning are fairly well known. Technically, the phenomenon may be described as follows:—

The centre of gravity of the aeroplane draws a spiral path with the wing rotating about it and therefore the axis of rotation does not pass through the centre of gravity. Moreover, the motion of the centre of gravity, as a rule, does

* Spinning is very clearly defined by Professor A. Bets, of Göttingen, in Volume IV. of Aerodynamic Theory, edited by E. W. Durand.

not lie in the plane of symmetry, with the result that the motion of one wing-tip is usually ahead of the other, which imposes a slideslip on the rotary movement giving an additional moment tending to increase the intensity of the already unstable rotary motion.

The attitude of the longitudinal axis of the aeroplane varies between sixty degrees and thirty degrees to the horizontal, the latter being a flat spin. It is doubtful if this attitude can get much less than thirty degrees and the wing still remain stalled.

The difference in the angle of attack of one wing to another varies approximately from twenty degrees in a slow spin, to seventy degrees in a fast spin. The average is usually thirty-five or forty degrees. The tail is usually operating at an angle from about thirty degrees to sixty degrees combined with a slideslip of about twenty degrees and often the fin and rudder, particularly the latter, are blanketed by the horizontal surfaces.

There are two principal dynamic forces present in the spin. The largest is the inertia couple which tends to raise the nose of the aeroplane. This couple is produced by the centrifugal force, due to rotation by the moment arm of this force and is usually expressed by the following formula :—

$$\tfrac{1}{2}\Omega^2 \sin 2\alpha \Sigma (Mx^2)$$

α = angle of incidence at the centre of the wing.
Ω = rate of rotation in radians per second.
M = mass.
x = distance from the centre of gravity.

This couple, under certain conditions of loading, can quite possibly exceed the available elevator control moments at thirty degrees incidence.

The other dynamic force present in the spin, is the gyroscopic couple, due to the gyroscopic force of the propeller and this is usually expressed by the following formula :—

$$lW\Omega \sin \alpha$$

l = moment of inertia of the propeller.
W = the rate of the rotation of the propeller.

This couple will increase the rate of the spin when it is in the opposite direction to the propeller rotation and it is quite possible in this case that the gyroscopic force may be greater than the added effectiveness given to the tail surfaces by the slipstream from the propeller.

In a normal fast spin, accelerations as high as 4 G. have been recorded. In a flat spin, accelerations, of course, depend on how far the pilot's seat is from the centre of gravity, but in this case, the accelerations are usually considerably slower. The lateral acceleration is very small.

As a rule, an aeroplane loses about two hundred feet per turn of a spin, but this is dependent on the wing loading and the altitude. A heavily loaded aeroplane at high altitude will lose considerably more; a completely flat spin considerably less. Each turn of a spin usually takes from one to four seconds and the radius of the turn varies from a few feet to several times the wing span. The angular velocity is from one to four radians per second.

As far as the author knows, the first deliberate spins in an aeroplane were attempted at the Bleriot School in France by one of the world's first aerobatic pilots, Adolphe Pegoud. His method was to put the aeroplane into a stall, and when it went into a spin he let go of the stick; because the Bleriot happened to be a particularly stable aeroplane, it would recover almost immediately.

The first pilot to carry out real experiments, in which he put an aeroplane deliberately into a spin and found out how to bring it out by use of the controls, was Major F. W. Gooden, of the Royal Flying Corps. This was in 1916. Immediately after this, during the rest of the war, the spin was used as a tactical manœuvre to escape from an opponent who got too close, but very little was

known about the theory of spinning and practically nothing with regard to the spinning characteristics of aeroplanes.

The first flat spin the author experienced was in 1918 in a navy training seaplane, which was built for a 200 h.p. motor. This motor was unsatisfactory and the aeroplane was therefore fitted with a 100 h.p. Curtiss OX. The OX was considerably lighter and the aeroplane, besides being under-powered, did not balance well. Difficulty was experienced with students spinning in these aeroplanes, although in every instance, the spins were so slow and so flat that no one was hurt. The author was detailed to investigate the trouble and succeeded in spinning himself in, as it was almost impossible to get sufficient altitude to find out the cause. At that time, the flat spin was not recognised and it was finally decided that it was just a bad aeroplane and the matter allowed to rest.

The next flat spin encountered was in a single-seater triplane in 1919. The only method of testing known at that time was to climb to a reasonably high altitude and spin the aeroplane deliberately. This particular aeroplane wanted to spin more than any other the author had ever flown. When put into a spin at 6,000 feet, he recalls thinking how interesting it was that the control column (the aeroplane was fitted with Dep controls) stayed right back against his chest. The spin was very slow and completely flat. At about 3,000 feet altitude, recovery was attempted, but the only result was that the attitude of the spin was changed. With the controls all the way forward, the aeroplane would spin in an inverted position, whereas by using the ailerons in the direction of the spin had practically no effect and reversing them made the spin much faster.

When, as a last resort, the throttle was involuntarily opened fully, the aeroplane recovered at about 100 feet altitude and upon landing and making an examination, it was found that the wing structure was loose at the fuselage. There were no further opportunities of testing this particular aeroplane, as shortly afterwards a student, in taxi-ing his seaplane up on the beach, became excited and ran into the triplane, unfortunately wrecking it completely. This experience rather naturally interested the author in the theory and practice of spinning and he has since experimented with all phases of this phenomena.

Spinning proclivities have apparently progressed inversely as aeroplane efficiency has increased and some authorities maintain that serious spinning is directly proportional to the wing loading. The author is not entirely in accord with the limitations imposed by this theory, but agrees that it is one of the influencing factors. Other things being equal, a heavily loaded aeroplane will undoubtedly spin faster than one with light wing loading, and, due to the built up momentum, will continue to do so with greater facility. On the other hand, there have been many training planes with light wing loading which had bad spinning characteristics and it might even be said that there are more bad spinners among experimental training aeroplanes than there are in the more heavily loaded commercial or military types. This may be influenced by the fact that the training aeroplane is not designed for high performance and usually has more projections, square corners, etc., than the military or commercial aeroplanes and all, or any one of these, may cause a bad air flow over the tail surfaces during a spin. One thing the author has definitely found to be true is that some heavily loaded aeroplanes will recover at a low altitude, when they will not at a high altitude. This would inferentially appear to be due to the difference in air density and consequent effect on its flow over the control surfaces. I believe that R. and N. Report No. 1663, with relation to " Air Density Effects in Spinning," disagrees with this, but there seems to be no other logical explanation and the phenomenon might, with advantage, be the subject of further investigation.

The United States Department of Commerce requires that open cockpit commercial aeroplanes of 4,000lbs. gross weight or less, and cabin aeroplanes of 3,500lbs. gross weight or less, must make six turns to the right and six to the left with recovery from the spin in a turn and a half under all conditions of load.

Cabin aeroplanes of between 3,500 and 4,000lbs. gross weight must be spun with light loads and also be tested for undue tendency to spin under full load conditions. Flying boats of over 2,500lbs. gross weight need not be subjected to spin tests unless they show an undue tendency to spin. The regulations provide, however, that any aeroplane, regardless of gross weight, may be subject to spin tests if there is any evidence of dangerous spinning characteristics. The reason for limiting the weight is that the majority of accidents due to spinning, have been in aeroplanes under 4,000lbs. gross weight, probably because most heavy aeroplanes are not likely to be flown by inexperienced pilots and do not lend themselves too readily to manœuvres which might result in a spin.

Many military aeroplanes are required to do more than six turns, particularly single and two-seater fighters, the heavier types are not required to make so many, two turns with recovery in one being the usual requirement.

During the course of investigating the practical aspects of spinning, a number of highly interesting reactions have been noticed, some being quite impossible to reproduce in a wind tunnel, even of the free spinning type. For instance, the method of entering the spin has a great deal to do with the type of spin produced. Entering the spin fairly fast (with a snap roll) will have the same effect as making two to three turns of a spin which was started from a stall.

There seems to be no definite way of predicting what a given aeroplane will do when spun.

There are some general rules which were found to be most effective in recovery from almost all conditions, and particularly in a prolonged spin. One is that the elevator should be held all the way back, the rudder controls should be held all the way in the direction of the spin, and the ailerons should be held in a neutral position for at least two or three turns before recovery is attempted, as when the controls are moved to the full extent of their throw from one direction to the other, the pilot is sure that the full range of control deflection is available. Also it is found that when the controls are full over in this manner, the spin is much steadier.

An unsteady or an oscillating type of spin will greatly affect the mental condition of the pilot, and the author, under certain circumstances, has several times found himself starting operations for recovery, different to those he actually intended to perform.

Another rule in recovery is that the rudder should first be moved fully *against* the spin and then, after an additional one half turn, the stick should be moved forward all the way. Both of these movements should be quite rapid, but not jerky. This position should be maintained until the spin stops. The author has personally experienced several instances where four or five turns were required to stop a spin, and the temptation to try something else was very great, but in almost every instance, the spin will eventually stop if this position is maintained.

Opening the throttle has been advocated as a means of recovery, but due to gyroscopic action, it is quite as likely to make the spin worse and almost invariably causes bad vibration, apart from the probability of the motor stopping during a long spin. Slow movement of the controls is likely to be ineffective and there have been many cases of a plane continuing to spin with the controls completely reversed when they were operated slowly, whereas in the same machine, if they were moved more rapidly, complete recovery was effected.

It is very dangerous to ease the stick part of the way forward during the spin, as this gives one the false impression that all that is necessary to check the spin is to move the stick slightly more forward, but should the spin become flat or uncontrolled in any way, there is not enough forward motion of the stick left to make recovery certain. The only course left then is to bring the stick all the way back and start recovery over again.

There are no doubt many cases where these rules may not seem to apply, as some aeroplanes will recover with the rudder alone held in neutral position; others

with the rudder reversed and the stick all the way back, but nearly all will recover if the procedure as outlined in the foregoing is followed.

The author has heard of instances where the pilot claimed that when standing up in the cockpit getting ready to jump, the spin stopped. There are several possible reasons for this, such as change in centre of gravity, air pressure on the pilot's body, and more probably leaving the controls in neutral for an appreciable time. The author has flown aeroplanes that had bad spinning characteristics, but if all controls were released, the spin would eventually stop.

Some interesting paradoxes are encountered in spinning and spin control and the author recalls several planes on which, if the ailerons were reversed, it was difficult to check the spin. On the other hand, a small aeroplane which he owned would start to spin much more quickly if it were aileroned into the spin and during the first two or three turns, if the ailerons were reversed, the spin would stop immediately, even though the rudder and stick were held full on. If after three or four turns, however, the ailerons were reversed, it would spin much faster and take several more turns to recover.

The importance of using the rudder before the stick in all cases is that reversing the rudder tends to check the rate of rotation and nose the aeroplane down, and the blanketing of the rudder by the elevator is generally less when the elevator is up. It follows, therefore, that while the rate of rotation is being checked by the rudder, the elevators become increasingly effective. If the elevators are put forward before the rudder, the rate of rotation of the spin generally increases and the blanketing of the rudder is likely to be greater. This will vary somewhat with the tail design, but it has been found to be generally true of all aeroplanes.

The term " flat spin " is often erroneously applied to any bad spins, but the author has experienced very severe spins where it was anything but flat. One of the most serious was that of a training plane where the spin was very fast, almost straight down and the controls became completely ineffective. He actually tried to " bail out," but the speed of rotation was so high he was unable to do so, due to centrifugal force. However, after following the procedure already described, the controls became effective and the aeroplane recovered.

It is impossible to stress too highly the necessity of getting plenty of altitude in spinning a new aeroplane and also increasing the number of turns gradually, first doing about a quarter turn, then one half, one, one and one half, two, etc., depending on the reaction of the aeroplane. It is also necessary to observe carefully the control forces which build up. These factors vary greatly, but after much experience one can estimate quite accurately whether or not the spin will be severe or not by the size of the control surfaces and the size and weight of the aeroplane.

A very important reason for getting considerable experience in spinning normal aeroplanes before attempting the testing of new ones, is a psychological one. It is known that the inner ear comprises a membraneous labyrinth containing a fluid. This fluid is set in motion after two or three turns of a spin and this motion persists for some little time after the spin has stopped. The impulses from this fluid are transmitted to the brain and then from the optic nerve to the eye, driving it to one side. A corrective effort on the part of the pilot pulls the eye to the opposite side and an oscillation is set up. The result is that after a number of turns, even though the pilot has recovered from the spin, his senses tell him he is still spinning, and as a result he is very liable to over-control and fall into a spin in the opposite direction. This condition does not seem to get any worse after three or four turns, but it is a question of training to be able to recognise it.

Another and even more dangerous effect, and one that does grow greater with the number of turns, is due to the heavy centrifugal force in the spin, draining the blood from the brain, resulting in first haziness, then dizziness, and then, if too prolonged, unconsciousness. Some pilots are much more affected than

others, but the condition can be ameliorated considerably by doing a great deal of prolonged spinning.

Recently the author had to demonstrate a heavy observation seaplane which fortunately required only two turns for recovery. The spin up to two turns was not unusual, but the reverse load built up in the stick was so great that he displaced several of his ribs in the effort required to push it forward.

This particular aeroplane was fitted with both slots and flaps on the upper wing. With flaps down and slots open, it would spin quite readily, but paradoxically the control forces were completely reversed. It required much force to keep the aeroplane in the spin, and when the stick was released it would move forward and the spin would immediately stop. As it was only necessary to demonstrate the possibility of recovery from a spin, the author did not try to hold it for more than one turn. Spinning with the slots open and the flaps closed was not attempted. The slot installation was not good, as they opened at a speed which was much too high.

It is often claimed that the addition of wing tip slots prevents spinning. The author has had considerable spinning experience with slots; has flown many aeroplanes with and without slots, and personally owned an Avro Avian for several years. Sometimes it would be impossible to spin this aeroplane and at other times it would spin viciously. The same was found to be true of the De Havilland Moth, and was probably because the aeroplane was not properly rigged.

The author does not think there is any question that slots help an aeroplane with a wing section which stalls very abruptly, such as the old R.A.F. 15. The Vought Corsair, which the author tested a great deal, was known to be a very bad spinner, but when equipped with slots (the slots were fitted with a latching device to hold them shut) would recover from a flat spin in a turn or a turn and a half when the slots were unlatched. The same aeroplane, however, when put into a spin with the slots open (which was difficult, although possible) would spin flat quite readily.

Conversely slots were put on a Curtiss Hawk, which had never been a bad spinner, but it became almost uncontrollable when the slots were opened during a spin. A slight element of uncertainty might enter into this as it was impossible to see the slots while flying and the rotational forces might effect the opening of one slot.

There is certainly no doubt but that a slot increases the angle at which a wing stalls, but in spinning modern aeroplanes with a high left wing, it is a generally recognised rule that if the aeroplane is difficult to put deliberately into a spin, there will probably be insufficient control to get it out of any accidental spin. The author believes this might also be true in the case of a slotted aeroplane, although he has not had any occasion to test this theory, and as far as he knows, little has been done in the last few years on the testing of slotted wings in spins in America.

A wire braced biplane will often change its spinning characteristics when slightly out of rig and even approved aeroplanes which do not fly straight because they are out of rig should never be spun unless at considerable altitude, and even then, great care should be taken in the spinning.

Instances have occurred when students have spun training planes into the ground or had to leave them with a parachute, although they were of a type that had never before given any indication of bad spinning, the inference being that the plane was out of rig.

An aeroplane will generally spin quite differently to the right than to the left because it is rigged to compensate for the motor torque in level flight and also because the fin is rigged to offset the slipstream effect. Changes in weight and centre of gravity positions also often effect the spinning characteristics.

It is generally assumed that a bad spin is more probable in a tail heavy condition, but there seems to be some uncertainty as to whether this is due to the balance, or because it is easier to stall in this condition. Several planes have been

encountered which spun more viciously with full foreward C.G. than in any other way.

It has also usually been assumed that a rearward load on the stick is an indication of a flat spin. This is not always the case. If, however, it is accompanied by a rise in the nose of the aeroplane during the spin, it may be considered an indication that the spin will be flat.

Retractable landing gear, particularly with the wheels down, may cause bad spinning, although there should be no reason to attempt a prolonged spin under these conditions.

Military aeroplanes are required to be spun with bombs on the wings and in some instances with only one bomb on one wing. This usually makes the recovery sluggish, but otherwise does not seem to have any adverse effect on the spin.

The addition of floats causes bad spinning characteristics in many cases, because of the additional fin area of the floats (or float) being too far forward. This can usually be corrected by the addition of a small fin on the underside of the fuselage, where the tail wheel or tail skid would have been. This fin is not always necessary, but is required on many American commercial aeroplanes. The additional weight of the floats does not seem to have any detrimental effect, other than making the recovery somewhat more sluggish.

A device known as a spin chute is now in almost universal use in America in spinning experimental military types and is rapidly becoming standard equipment for spin tests on all types of aeroplanes. It consists of a small parachute about six feet in diameter which is attached to the tail by a twenty or thirty foot length of cable and stowed somewhere on the tail.

The parachute when released during an uncontrolled spin acts very much in the same manner as a sea anchor and pulls the aeroplane straight. It is then detached and the aeroplane is brought out of the resultant dive.

The important thing to observe in using this device is its location on the aeroplane. Several cases have been reported of the parachute lying across the tail where it caught and failed to open. There is of course, considerable dead air around the tail during the spin and it is important that the parachute be clear in order to open properly. It is also important to have the cable and fittings holding the chute strong enough. This should be tested by releasing the chute while in level flight and then cutting it loose over the field.

The best location is obviously on the top of the fin, but, by placing it there, it may cause interference with the rudder. If it is fastened in the open, it will probably be torn loose before it is needed.

In some of the early installations, it was customary for the pilot to carry the parachute in the cockpit with the cable laid along the turtle deck and fastened securely with adhesive tape. The parachute was then wrapped in a heavy weight so that it would be thrown clear of the aeroplane. This, of course, is very awkward, and the chute may get tangled up with something in the cockpit. There is still room for considerable experiment to decide the best location of the chute, so that eventually it may be installed on any aeroplane quite readily. In the near future it may possibly be standard equipment on all military aeroplanes, or at least on those types that may be spun in the normal course of flying. Already it has definitely saved several aeroplanes, which subsequently, with slight modification, were cured of their bad spinning characteristics. This alone has proved the value of the device.

In conclusion, the author believes that there is a great deal yet to be learned about the phenomenon of spinning. Valuable research work is being done in spinning tunnels, and also in actual practice, but it is still almost impossible to predict the spinning characteristics of a given aeroplane. These characteristics are greatly effected by the wing curve, fillets between the wing and the fuselage, by the length of the tail, and the size and position of the control surfaces.

The National Advisory Committee of Aeronautics has done considerable research work with recording instruments, using an optical recording system to eliminate

errors due to the acceleration effects in the mechanism. These instruments comprise a recording accelerometer, a recording turn meter and a recording air speed indicator, and are used for measuring angular velocities of aeroplanes in any manœuvre, as well as recording the speed. Although a great deal of work has been done with these instruments, most of it has been on military aeroplanes and very little has been published and the results are still consideerd of a confidential nature and therefore cannot be divulged.

The author has flown aeroplanes which had every indication of being bad spinners, but were perfectly stable, whereas others that looked stable had bad spinning characteristics. As an example, it has been generally thought that negative stagger would be detrimental to good spinning. There is a well known example of an American aeroplane with negative stagger and yet its spinning characteristics have been excellent. A great deal of data has been gathered which is undoubtedly of assistance to both the designer and test pilot in enabling some prediction of the spinning characteristics of an aeroplane, but there is still a great deal more to learn before it will be possible to predict positively these characteristics under all conditions of loading and handling.

A PRACTICAL EXERCISE ON THE STRENGTH OF RIGID-JOINTED FRAMES.

By Capt. J. Morris, B.A.

Introduction.

Recent contributions to the theory of structures with particular reference to the design of aeroplanes have dealt with the theory of frames in which the members are rigidly connected together at the joints; the object being to ascertain the degree of increase in strength of the individual members due to the restraint at their ends supplied by the contiguous members.

Briefly, when a member forms part of a rigid-jointed structure it acquires a rigidity arising from the rest of the structure. The amount of rigidity given by the rest of the structure may vary from zero end fixation to full encastreing.

The student of advanced structures may be materially helped in grasping the underlying principles if in parallel with working an example he can carry out a test on a simple frame, checking not only the mathematical prediction of mode of failure and degree of fixation, but also the validity of his basic assumptions.

A triangular frame is suggested for the test, being the simplest to construct, and the failing load for the compression member is worked out below. In carrying out the test the student would check experimentally the degree of fixation of this member by measurement of deflections and rotations for comparison with their calculated values. It would also be useful to compare the actual and calculated failing loads.

The sizes of members in the example have been chosen so that failure should occur as a result of the maximum fibre stress exceeding its failing value at a load a little below the true critical value (taking account of the end constraints), but well above the critical load of the same member considered as pin-jointed at the ends.

Description of Simple Test Frame.

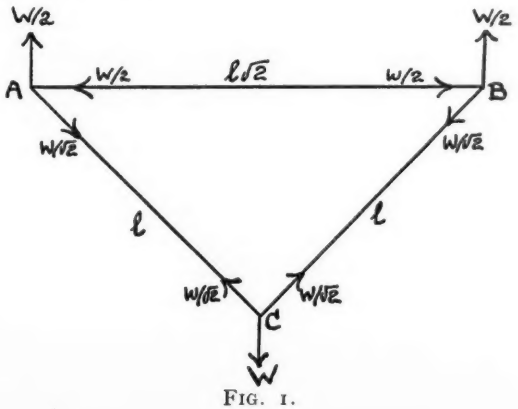

Fig. 1.

Referring to Fig. 1, let ACB be a right-angled triangle such that $AC=CB=l$, say. Then $AB=l\sqrt{2}$. Let all the sides of the triangle be composed of tubes of the same material and cross-section and let the joints A, B, C, be rigid. Let AB be suspended horizontally and let a load W be applied vertically at C. The load W is gradually increased until failure of the frame takes place, the members being prevented from failing in the plane normal to ACB.

THEORETICAL INVESTIGATION OF THE STRENGTH OF THE LOADED FRAME.

Clearly the members AC, BC will be in tension while the member AB will be in compression.

For the member AB let

$$(\tfrac{1}{2}l\sqrt{2})\sqrt{(W/2EI)}=\alpha$$

then for the members AC, BC

$$\beta=\tfrac{1}{2}l\sqrt{(W/EI\sqrt{2})}=0.84\ \alpha.$$

Due to the load W let the point C drop a vertical distance Y relative to the line AB while each of the points A, B moves inwards a distance X.

Then for the member AB

$$2X=\tfrac{1}{2}W\ (l\sqrt{2}/AE)$$

and for the members AC, BC

$$(Y-X)/\sqrt{2}=(W/\sqrt{2})\ (l/AE).$$

Let

$$l/AE=x_{11}$$

then we find that

$$X=(W/2\sqrt{2})\ x_{11}$$

$$\text{and}\quad Y=W\ (1+1/2\sqrt{2})\ x_{11}.$$

Let ϕ be the angular rotation in a clockwise direction of the point A. By symmetry the angular rotation of the joint B will also be ϕ, but in the opposite direction. There will be no rotation of the joint C.

Now for any member, say AC, let δ_{AC} be the deflection of C relative to A measured at right angles to the original line of AC and in a clockwise direction, then if M_{CA}, M_{AC} are the bending moments at ends C, A of the member measured clockwise from the point of view of the action of the joints on the ends of the member, then it may be proved that

$$M_{CA}=-(6EI/l^2)\ (\delta_{AC}/\phi\ \alpha/2)+(4EI/l)\ \{\phi\ (\alpha)/\psi\ (\alpha)\}\ \phi_C + (2EI/l)\ \{f\ (\alpha)/\psi\ (\alpha)\}\ \phi_A$$

where $f\ (\alpha)$, $\phi\ (\alpha)$, $\psi\ (\alpha)$, are the usual Berry functions (regard being had to compression or tension); ϕ_C is the rotation of the joint C and ϕ_A is the rotation of the joint A, both angles being measured clockwise.

Similarly

$$M_{AC}=-(6EI/l^2)\ (\delta_{AA}/\phi\ \alpha,2)+(4EI/l)\ \{\phi\ (\alpha)/\psi\ (\alpha)\}\ \phi_A + (2EI/l)\ \{f\ (\alpha)/\psi\ (\alpha)\}\ \phi_C.$$

Coming now to the particular example we have

$$\delta_{AB}=0$$

$$\phi_A=-\phi_C=\phi\ \text{say}$$

$$M_{AB}=(4EI/l\sqrt{2})\ [\phi\ (\alpha)/\psi\ (\alpha)-(\tfrac{1}{2})\ f\ (\alpha)/\psi\ (\alpha)]\ \phi$$

$$\delta_{CA}=(Y+X)/\sqrt{2}=W\ (\tfrac{1}{2}+1/\sqrt{2})\ x_{11}$$

$$M_{AC}=-(6EI/l^2)\ \{W\ (\tfrac{1}{2}+1/\sqrt{2})\ x_{11}/\Phi\ (0.42\ \alpha)\} + (4EI/l)\ \{\Phi\ (0.84\ \alpha)/\Psi\ (0.84\ \alpha)\ \phi\}.$$

But from the equilibrium of the joint

$$M_{AB}+M_{AC}=0$$

$$\therefore\ \phi=(6EI/l^2)\ \{W\ (\tfrac{1}{2}+1/2)\ x_{11}\}\ /\ \{\Phi\ (0.42\ \alpha)\ [(4EI/l\sqrt{2})\ \{\phi\ (\alpha)/\psi\ (\alpha) - (\tfrac{1}{2})\ f\ (\alpha)/\psi\ (\alpha)\} + (4EI/l)\ \{\Phi\ (0.84\ \alpha)/\Psi\ (0.84\ \alpha)\}\ ]\}$$

or since

$$\phi(a)/\psi(a) - (\tfrac{1}{2}) f(a)/\psi(a) = a/2 \tan a$$

$$\phi = \{ 3W(1+1/\sqrt{2})x_{11} \} / \{ l\Phi(0.42a)[a/\tan a + 2\sqrt{2}\{\Phi(0.84a)/\Psi(0.84a)\}] \}$$

Hence

$$M_{AB} = \{ (EI\sqrt{2}/l)(a/\tan a) 3W(1+1/\sqrt{2})x_{11} \} / \{ l\Phi(0.42a)[a/\tan a + 2\sqrt{2}\,\Phi(0.84a)/\Psi(0.84a)] \}.$$

Now by definition

$$W = (4EI/l^2)a^2$$

and also

$$x_{11} = lk^2/EI.$$

Hence

$$M_{AB} = \{ 12(1+\sqrt{2})(a^3/\tan a)(EIk^2/l^3) \} / \{ \Phi(0.42a)[a/\tan a + 2\sqrt{2}\{\Phi(0.84a)/\Psi(0.84a)\}] \}$$

and

$$(M_{AB})_{max} = \{ 28.97(a^3/\sin a)(EIk^2/l^3) \} / \{ \Phi(0.42a)[a/\tan a + 2.83\{\Phi(0.84a)/\Psi(0.84a)\}] \}.$$

The corresponding maximum fibre stress due to bending will be

$$f_{max} = \{ 28.97(a^3/\sin a)(Ehk^2/l^3) \} / \{ \Phi(0.42a)[a/\tan a + 2.83\{\Phi(0.84a)/\Psi(0.84a)\}] \}.$$

Clearly instability failure will occur when

$$a/\tan a + 2.83\{\Phi(0.84a)/\Psi(0.84a)\} = 0.$$

The smallest value of a to satisfy this equation is approximately

$$a = 2.6 \text{ radians.}$$

In which case

$$W = 4EIa^2/l^2$$

$$\text{or } W = 27.04\,EI/l^2.$$

The instability failing load for AB, when considered as a pin-jointed strut will be given by

$$W = (4EI/l^2)(\pi/2)^2 = \pi^2 EI/l^2 = 9.87\,EI/l^2.$$

Failure, however, may take place before the instability load is reached as the result of the maximum fibre stress exceeding its failing value.

To take a specific case, suppose the tubes of which the test triangle is composed are of T.45, $\frac{3}{4}$in. o.d. and 20 G. Also let $l = 30$in. For the allowable load we take the maximum stress as the 0.2 per cent. proof stress (p_2) of the material. Hence we have

$p_2 = 40$ tons/sq. in.
$E = 28.8 \times 10^6$ lb./sq. in.
$l = 30$in.
o.d. $= 0.75$in.
$h = 0.375$in.
$k = 0.2528$in.

The requisite a is therefore given by

$$40 \times 2{,}240 = W/2A + M_{max}/Z$$

$$= \{ 4 \times 28.8 \times 10^6 \times (0.2528)^2 a^2 \} / \{ 2 \times 30^2 \}$$

$$+ \{ 28.97 \times 28.8 \times 10^6 \times 0.375 \times (0.2528)^2 (a^3/\sin a) \} / \{ 30^3 \Phi(0.42a)[a/\tan a + 2.83\{\Phi(0.84a)/\Psi(0.84a)\}] \}$$

or

$$206.17 = 16.09\,a^2 + a^3/\{ \sin a \Phi(0.42a)[a/\tan a + 2.83\{\Phi(0.84a)/\Psi(0.84a)\}] \}$$

The appropriate value of a which satisfies this equation is given by

$$a = 2.57 \text{ approximately}$$

to which corresponds a failing load of

$$W = 25.4\, EI/l^2$$
$$\text{or } W = 4{,}065\text{lb.}$$

It will be observed that in the particular case chosen the value of α for which the allowable stress will occur is very close to the α for which critical instability will occur, viz., $\alpha = 2.6$ previously found.

The critical load will therefore be given by

$$W = 29.04\, EI/l^2$$
$$\text{or } W = 4{,}330\text{lb.}$$

This may be compared with the corresponding failing load when the member AB is regarded as pin-jointed.

The value of $l/k = 30\sqrt{2}/0.2528 = 168$ app.

According to the Air Ministry strut strength sheet for T.45 we have for this value of l/k an allowable stress of 9,500 lb./sq. in. This corresponds to an allowable load of approximately 1,530lb.

The instability load in this case is 1,580lb.

In the course of the test the following quantities may be measured

(1) Y (deflection of C relative to the line AB)
$$= W\,(1 + 1/\sqrt{2})\,(l/AE)$$

(2) $$\phi = \{\, 3W\,(1 + 1/\sqrt{2})\, x_{11} \,\} \,/\, \{\, l\Phi\,(0.42\,\alpha)\,[\alpha/\tan\alpha + 2\sqrt{2}\,\{\,\Phi\,(0.84\,\alpha)/\Psi\,(0.84\,\alpha)\,\}\,]\,\}$$

or

$$\phi = \{\, 20.48\,(k^2/l^2)\,\alpha^2 \,\} \,/\, \{\, \Phi\,(0.42\,\alpha)\,[\alpha/\tan\alpha + 2\sqrt{2}\,\{\,\Phi\,(0.84\,\alpha)/\Psi\,(0.84\,\alpha)\,\}\,]\,\}$$

where α is given by

$$\alpha^2 = l^2 W/4EI.$$

ABSTRACTS AND NOTICES

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(Prepared by R.T.P.)

No. 39. SEPTEMBER, 1936.

A Simple Method for Calculating Stream Functions. (H. Steuding, Z.A.M.M., Vol. 16, No. 1, Feb., 1936, pp. 20-22.) (1730 Germany.)

The author shows how the stream function of a domain of variable position and shape can be calculated by means of con-formal representation.

The paper thus forms a useful extension of the classical case of the elliptic cylinder treated by Lamb. (Textbook of Hydrodynamics.)

On the Stability of Double Row Vortices in a Rectangular Channel. (I. Isao, Comp. Rend., Vol. 202, No. 23, 8/6/36, pp. 1908-1910.) (1803 France.)

The following conclusions apply to the double row of vortices of unequal strength:—

1. Two configurations are possible, one symmetrical, the other staggered.
2. The symmetrical arrangement is always unstable, the sign of the vortices being opposite in the two rows.
3. The alternate arrangement is unstable if the sign of the vortices is the same in the two rows.

Influence of Fluid Boundaries on the Aerodynamic Characteristics of Wing Surfaces. (A. Toussant and S. Pirko, Comp. Rend., Vol. 202, No. 23, 8/6/36, pp. 1911-1914.) (1804 France.)

In two previous publications (pp. 1753-1756 and pp. 1834-1836, Comp. Rend., Vol. 202), the authors have investigated by the method of images, the boundary effects of guided and free jets respectively. The present paper deals with experimental confirmation of the calculated effects.

The wing tested had a maximum thickness of 4 cm., chord 18 cm. and span 83 cm. The width of the fluid jet was 22 cm. By applying calculated correction to the angle of incidence, satisfactory agreement of the experiments with those obtained in an infinite fluid was obtained, provided the angle of incidence was not large.

Wave Resistance: The Mutual Action of Two Bodies. (T. H. Havelock, F.R.S., Proc. Roy. Soc., Vol. 155, No. 886, 1/7/36, pp. 460-471.) (1849 Great Britain.)

A new method is given for calculating wave resistance from the source distribution equivalent to the body producing the waves. Results are obtained for a simple case representing two small spheres in various relative positions. With the two spheres in the line of motion, the resistances differ by certain forces of action and reaction and also by the wave interference effects, which are assigned entirely to the following sphere.

Taking the two spheres abreast, the results are interpreted as showing the effect of a vertical wall upon the resistance of a sphere.

Finally, with the spheres in any relative positions, it is shown that effects of wave interference occur when the following sphere lies within the wave pattern produced by the leading sphere, and arise from both the transverse waves and the diverging waves.

A Note on the Measurement of Total Head and Static Pressure in a Turbulent Stream. (S. Goldstein, Proc. Roy. Soc., Vol. 155, No. 886, 1/7/36, pp. 570-575.) (1850 Great Britain.)

If p is the true mean static pressure, q the resultant mean velocity, and q_1 the resultant turbulent velocity, it is proved that a total head tube in a turbulent stream measures $p+\frac{1}{2}\rho q^2+\frac{1}{2}\rho q_1{}^2$. Reasons are given for assuming that if the turbulence is isotropic a static pressure tube measures $p+\frac{1}{6}\rho q_1{}^2$.

On the Static Pressure in Fully Developed Turbulent Flow. (A. Fage, Proc. Roy. Soc., Vol. 155, No. 886, 1/7/36, pp. 576-596.) (1851 Great Britain.)

The relation between the reading of a static pressure tube (S) and the true average static pressure ($\overline{p}$) is expressed in the form

$$S=\overline{p}+K\rho\,[\overline{v^2}+\overline{w^2}],$$

where v and w are the cross components of the turbulent velocity, and K has a characteristic value for the same tube in turbulent streams of the same kind. The values of K obtained for a static tube of common design (12 holes spaced 30°) were 0.28 (circular pipe) and 0.22 (rectangular pipe).

Information has been obtained on the relation between the values of $\overline{p}$ and $\rho\overline{q^2}$ (where $\overline{q^2}=\overline{u^2}+\overline{v^2}+\overline{w^2}$) in the turbulent wake behind a long circular cylinder.

The sum of the values $\overline{p}$ and $\frac{1}{2}\rho\overline{q^2}$ was equal to the pressure just outside the wake, and it is concluded from this result, and the known nature of the distributions of $\overline{p}$ and $\frac{1}{2}\rho\overline{q^2}$, that $(\overline{p}+\frac{1}{2}\rho\overline{q^2})$ is constant across the wake.

Note on the Gliding of a Plate on the Surface of a Stream. (A. E. Green, Proc. Camb. Phil. Soc., Vol. 32, Part 2, 1936, pp. 248-252.) (1915 Great Britain.)

This note deals with the complete solution of the two-dimensional gliding of a plane plate on a stream of infinite depth. The results are expressed in terms of the actual length of the plate and hold for any angle of incidence.

In a previous solution by Wagner (Z.A.M.M., Vol. 12, No. 4, Aug., 1932, pp. 193-215, in course of translation) the spray is assumed parallel to the plate, in which case the lift increases linearly with the spray thickness. In the present solution, the direction of the spray alters with its thickness, the lift at first increasing and then decreasing to the limiting value of the classical Rayleigh flow (plate in infinite stream).

The Formation of Shock Waves in Aerodynamic Fields at Boundary Velocities Below the Velocity of Sound. (L. Gabeaud, Comp. Rend., Vol. 201, No. 27, 30/12/35, pp. 1460-1461.) (1935 France.)

The author has previously obtained a value for the depression existing on the base of a projectile in flight in term of the velocity of the air V at the edge. Combining this with the condition of adiabatic flow, it follows that V becomes equal to the local speed of sound when the velocity at infinity = 0.86 local velocity of sound.

Experimental resistance figures obtained for shells show a discontinuity round about this figure.

A Numerical Expression for the Turbulence of Wind Channels. (A. Foch, Comp. Rend., Vol. 201, No. 27, 30/12/35, pp. 1462-1463.) (1936 France.)

The author proposes to record rapid pressure fluctuation by exposing an electrostatic microphone (suitably rectified) to the air current. From the reading so obtained, the amount due to sound only is subtracted and the remainder expressed as a percentage of the dynamic head. The difficulty is to obtain correct response over the large frequency range (10 to 500 second).

Experiments with hot wire instruments are in progress.

Movements of Contaminated Surfaces. (R. Merigoux, Comp. Rend., Vol. 202, No. 25, 22/6/36, pp. 2049-2051.) (1941 France.)

Two photographs are shown of waves on the surface of " clean " and " contaminated " water respectively (in the latter case a trace of oleic acid has been added). Both surfaces show capillary ripples preceding the wave proper.

In the case of the clean surface, these ripples originate at the wave front. In the case of the oily surface there exists a considerable gap of smooth surface between the two sets of waves.

The phenomenon is associated with the friction between the monomolecular layer and the supporting liquid and is being studied quantitatively.

A Method of Estimating the Aerodynamic Effects of Ordinary and Split Flaps of Airfoils Similar to the Clark Y. (H. A. Pearson, N.A.C.A. Tech. Note No. 571, June, 1936.) (1946 U.S.A.)

An empirical method is given for estimating the aerodynamic effect of ordinary and split flaps on airfoils similar to the Clark Y. The method is based on a series of charts that have been derived from an analysis of existing wind tunnel data. Factors are included by which such variables as flap location, flap span, wing aspect ratio, and wing taper may be taken into account. A series of comparisons indicate that the method is suitable for use in making preliminary performance calculations and in structural design.

Some Problems on Aerodynamics of an Aeroplane with Split Flaps. (A. Martinov, Aeron. Eng. (U.S.S.R.), No. 6, June, 1936, pp. 13-32. Available as Translation No. 335.) (1954 U.S.S.R.)

The following are the main conclusions:—

1. With V_{min} = const. the speed range is a function of the cube root of Cy_{max}. Hence the effect of any further increase of Cy_{max} produced in any way will become continuously less with respect to an increase in the speed range.

2. A cut-out in the middle section of the rear flap causes a much greater loss of effectiveness than cut-outs of the same size at the end of the wing.

3. The relative thickness of the wing profile has the greatest influence with respect to the increase of the Cy_{max} of a wing with rear flaps.

4. The slope of the flow in the region of the tail unit behind a wing with displaced rear flaps is greater than that calculated by the formula of Mogilevski

and Ostoslavski. The higher the tail unit is set on the aeroplane the less difference there is between the calculated and the experimental results.

An Analysis of the Influence of Drag on Speed of Modern Transport Aeroplanes. (F. S. Chamberlin, Aero Digest., Vol. 29, No. 1, July, 1936, pp. 26-28.) (2021 U.S.A.)

The outstanding means of improving speed performance are:—

(*a*) Better lift increasing devices so that higher wing loading can be used.

(*b*) Increased taper of wing.

(*c*) Full retraction of landing gear and tail wheel.

(*d*) Improvement in fuselage streamlining (retractable wind shield).

(*e*) Development of engines suitable for installation inside the wing (Junkers horizontally opposed piston engine).

Supersonic Wind Tunnel at Guidonia. (Inter Avia., No. 340, 9/7/36, p. 6.) (2049 Italy.)

The tunnel section is 40 × 40 cm. and maximum speed is 638 m./sec. (1,440 m.p.h.). The air current is produced by an axial blower (3,910 r.p.m.) absorbing 2,900 b.h.p. The tunnel is sealed against the external atmosphere and air densities can be adjusted to cover the range ground to 90,000 feet altitude. The flow is rendered visible by proper illumination and the shock wave at a model wing occurring at an air speed of 1,100 m.p.h. is illustrated.

Preliminary Report of Tests on "Pou du Ciel" at Chalais-Meudon. (Les Ailes, No. 787, 17/7/36, p. 11.) (2051 France.)

If dived beyond a certain angle the machine becomes unstable, oscillates and turns on its back. These phenomena cannot be prevented by any control movement of the pilot. Experiments are being continued to study what modifications, if any, of design variables will obviate this danger. Stability in horizontal flight and when climbing appear to be satisfactory.

Body and Tail Moments in Spin. (H. B. Irving, Airc. Eng., Vol. 8, No. 90, August, 1936, pp. 221-222.) (2339 Great Britain.)

In a previous article by Korvin-Kroukosky (Airc. Eng., Vol. 5, May, 1933, pp. 105-112) the view was expressed that during a flat spin, the body and tail were largely shielded by the wings.

The author shows that this is erroneous. The tail plane is responsible for the blanketing and even reversal of the fin and rudder. The body, far from working ineffectively in a wide wake behind the stalled wings, will provide a very important control, provided it is of suitable shape and dimensions.

The shielding of the fin and rudder by the tail plane can be governed by:—

(1) Positioning of tail plane.

(2) Fin and rudder shape.

Estimation of Moments of Inertia of Airplanes from Design Data. (H. W. Kirschbaum, N.A.C.A. Tech. Note No. 575, July, 1936.) (2371 U.S.A.)

A method of determining the moments of inertia of an airplane from design data of the weights and locations of the component parts is described. The computations required to ascertain the centre of gravity position are incorporated with the calculations of moments of inertia. A complete set of data and calculations for a modern airplane is given to illustrate the procedure. From a comparison between calculated and measured values it is believed that the moments of inertia can be estimated within 10 per cent. by the use of this method.

Wing Fuselage Interference. (A. L. Boyajian, Aero Digest., Vol. 29, No. 2, August, 1936, pp. 28-30.) (2419 U.S.A.)

Wind tunnel measurements were carried out on a low wing monoplane with tapered wing roots and were compared with those for conventional wing root construction, both filleted and unfilleted. The experiments show that a reduction in wing chord (symmetrical taper) is beneficial and produces higher lift and better flow up to angles of incidence of 7°. An explanation is given on boundary layer theory (induced lift).

Contribution to the Problem of Airfoils Spanning a Free Jet. (J. Stüper, L.F.F., Vol. 12, No. 8, 25/12/35. Translation N.A.C.A. Tech. Memo. No. 796, June, 1936.) (2632 Germany.)

After a brief discussion of previous work on an unwarped wing of constant chord spanning a free jet, the computation of the circulation and lift distribution for different forms of warped wings spanning rectangular and circular jets was carried out. The computed values are compared with test values and the agreement is found to be good. The effect of placing the wing eccentrically is slight and a suitable correction factor has been worked out.

Flow Phenomena on Plates and Airfoils of Short Span. (H. Winter, V.D.I. (Special Issue) (Aviation), 1936. Translation, N.A.C.A. Tech. Memo. No. 798, July, 1936.) (2634 Germany.)

Investigations on the flow phenomena round plates and cambered wings were carried out with the aid of force measurements, some pressure distribution measurements and photographic observation.

The experimental methods are described. The results show how nearly the lift line and lift surface theories agree with the experiment.

Scale Effect in Tank Tests of Seaplane Floats. (R. Schmidt, L.F.F., Vol. 13, No. 7, 20/7/36, pp. 224-237.) (2638 Germany.)

Experiments were carried out on two models (scale 1/2.5 and 1/5) and compared with full-scale measurements obtained with a special three component balance.

The comparison shows that the float model should possess at least a scale of 1/2.5 so as to ensure satisfactory agreement with practice. (Twelve references.)

Smoothing Out Waves of the Sea. (*Soviet Institute of Water Transport.*) (J. Am. Soc. Nav. Eng., Vol. 48, No. 3, August, 1936, pp. 447.) (2693 U.S.S.R.)

A series of parallel pipes carrying compressed air are submerged to a depth of some 30 feet beneath the surface of the water. Each pipe, 4 inches in diameter, is perforated with small holes several inches apart. When a wave passes over the apparatus, the jets of compressed air released through the perforations are stated to smooth the water surface.

With the use of strong " columns " of compressed air it is contended that a large wave could be completely levelled.

Tests with a " wave-breaker " in the harbour of Sebastopol (Black Sea) are reported to have shown that waves 3 or 4 feet in height could be reduced in force and height by 40 per cent. The " crests " were entirely smoothed out.

An application to flying boat harbours is contemplated.

A Simplified Application of the Method of Operators to the Calculation of Disturbed Motions of an Airplane. (R. T. Jones, N.A.C.A. Report No. 560, 1936.) (2799 U.S.A.)

The method is applied to the rolling motion produced by deflecting ailerons at low speed and sideslipping during two control turns respectively.

The airplane assumed in these calculations is a typical two-seater monoplane of 1,600lb. gross weight.

On the Mapping of the Velocity Potential and Stream Functions of an Ideal Fluid. (A. C. Erickson, Science (U.S.A.), Vol. 81, No. 2098, 15/3/36, pp. 274-275.) (2816 U.S.A.)

The writer describes a modification of the electrolytic method described by Relf (Phil. Mag., 48, 535, 1924). In place of the liquid electrolyte, sheets of conducting black silhouette paper are used, and the earphone and alternating current of Relf are replaced by a galvanometer and direct electric current.

Velocity potential lines about an aerodynamic form are obtained by cutting out the corresponding shape from the centre of the conducting sheet.

The streamline flow about a form can be plotted directly by cutting out the shape in a highly conducting material and placing it on the conducting paper, making certain that good contact is obtained.

Lead pencils can be used as electrodes and in this way the pattern is obtained directly on the paper for record purposes.

When quantitative accuracy is required, the paper is replaced by a more homogeneous material, such as stainless steel $\frac{1}{32}$-inch thick.

The Flow Around a Plane Wing with Aileron. (C. Schmieden, Z.A.M.M., Vol. 16, No. 4, August, 1936, pp. 193-198.) (2818 Germany.)

Wing and aileron being represented by two segments of straight lines, the author maps the exterior of this contour on a half-plane by starting from a special case of flow around it. The resultant and the moment of the air forces are then calculated by means of Blasius' formulæ.

Determination of the Air Forces on a Plane Wing with Aileron. (G. Ellenberger, Z.A.M.M., Vol. 16, No. 4, August, 1936, pp. 199-226.) (2819 Germany.)

The forces acting on a plane wing with aileron in non-stationary motion are determined taking into account the vortices breaking away from the trailing edge. To this purpose, the author calculates the velocity potential for the most general movement of the wing, which, by known formulæ, yields the air forces on the wing. Applications are made to the most general movement of a wing without aileron and to the stationary motion and the harmonic oscillations of a wing with aileron.

The Flow of a Fluid Streaming into a Straight Pipe of Annular or Circular Cross-Section. (W. Muller, Z.A.M.M., Vol. 16, No. 4, August, 1936, pp. 227-238.) (2820 Germany.)

When a viscous fluid streams into a narrow tube with cylindrical walls, there ensues an initial non-stationary motion which finally leads to the stationary Poiseuille flow. The author represents this motion analytically by means of an exact integral of the Stokes-Navier equations and studies it for different conditions of pressure.

The Destruction of Materials by Fluid Impact and Cavitation. (J. Ackaret and P. de Haller, Institut für Aerodynamik, E.T.H. Zurich, Sept., 1936.) (2821 Switzerland.)

In a recent paper (Z.V.D.I., 11/7/36, p. 863) Messrs. Schwarz and Mantel stipulate the existence of hydraulic pressures of the order of 10,000 kg./cm.^{2} in order to account for the observed destruction.

Direct pressure measurements (piezo electric) by the authors have failed to record pressures exceeding 1,000 kg./cm.^{2}. The objection raised that these experiments failed to record peak pressures of short duration has been met by new experiments in which the immersed material is subjected to blows of a pneumatic hammer, the pressure being transmitted by a close fitting piston.

In the case of cast iron, corrosion became marked after 90,000 blows (two hours), although there is absence of gas bubbles and the liquid (water or paraffin) is chemically inactive.

The authors suppose that the destruction is due to variation of transmission speed of compression wave in the material brought about by heterogeneous nature of the surface.

Variation of orientation of crystals will cause large differences in local stresses which ultimately cause the surface crystals to break loose. This applies especially to graphite in cast iron.

Air Pressure on Chimney Stacks of Circular Section. (J. Ackaret, Institut für Aerodynamik, E.T.H. Zurich, Sept., 1936.) (2822 Switzerland.)

It is well known that the resistance coefficient of smooth circular cylinders depends very markedly on Reynolds number and diminishes rapidly between $R_e = 0.15 \times 10^6$ and $R_e = 0.35 \times 10^6$.

The author shows that in the practical case of rough cylinders (bricks and mortar) the reverse is the case, the resistance coefficient increasing over the range $R_e = 0.1$ to 1×10^6.

The wind loading in practice is thus practically double that calculated from smooth cylinder tests.

Experimental Study of the Scour of a Sandy River Bed by Clear and by Muddy Water. (C. A. Wright, Bur. Stan. J. Res., Vol. 17, No. 2, August, 1936, pp. 193-206.) (2835 U.S.A.)

An experimental comparison was made of the scour produced in a bed of fine sand by muddy and clear water respectively. The object was to stimulate conditions existing in the Colorado River at the Boulder Dam before and after construction.

Critical velocities of the water were determined for incipient movement of the sand bed and were found to be greater by 10 per cent. for muddy water containing clay in suspension, than for clear water.

It is concluded that the clear water discharged at the Boulder Dam will cause greater scouring than the original river (without the dam).

The Effect of Side Wind on the Path of Projectile Fired from Aircraft. (P. de Valroger, Rev. de l'Arm. de l'Air, No. 85, Aug., 1936, pp. 850-862.) (2880 France.)

For speeds at present in use, the aerodynamic forces on the bullet are negligible. Observation of the smoke track of tracer bullets is apt to lead to erroneous conclusions as to actual flight path of bullet.

The normal shaped bullet will only lose stability at cross wind speeds approaching the velocity of sound. The type of motion then occurring will require further experimental investigation (spinning shell in supersonic wind tunnel).

On the Origin and Suppression of the Discontinuity in the Hydrodynamic Resistance of Seaplane Floats. (G. Sabathe, Comp. Rend., Vol. 202, No. 22, 2/6/36, pp. 1836-1838.) (2890 France.)

The observed discontinuity is usually associated with an increased influence of the frictional resistance (see N.A.C.A. Tech. Memos. No. 735 and 739). Model experiments show that there exist under these conditions regions of negative

pressure and partial cavitation on the lower float surface, especially in the neighbourhood of the step. This depression was relieved by allowing the back of the step to communicate with the atmosphere through a narrow channel (12 mm. wide). By this means the resistance of the float was reduced up to 25 per cent.

Effect of Reynolds Number and Turbulence on the Maximum Lift Coefficient of an Aerofoil. (P. Krasischikov, Trans. C.A.H.I., No. 268.) (2893 U.S.S.R.)

Wind tunnel measurements were carried out on C_a max. for the following profiles:—

R.A.F. 28, 38, 48, 34.
Clark YH.
Göttingen 387.

The profiles were divided into the following four groups:—

(1) Symmetrical and thin profiles.
(2) Medium thickness and small curvature.
(3) Thick profiles and average curvature.
(4) Sharp leading edge.

The effect of increasing R_e (at small turbulence) on C_a max. differs for the groups:—

(1) C_a max. increases rapidly.
(2) C_a max. diminishes slowly.
(3) C_a max. diminishes more rapidly.
(4) C_a max. increases very slowly.

Increasing the turbulence increases the effect in group 1 and changes the sign of $dC_a \text{ max.}/dR_e$ for groups 2-4.

Design, Construction and Efficiency of Wind Tunnels. (S. Hoerner, Z.V.D.I., Vol. 80, No. 32, 8/8/36, pp. 949-957.) (2894 Germany.)

Various types of construction (German, French and English) are described and the increasing popularity of the free jet tunnel is noted.

The efficiency of the tunnel is sometimes defined as the ratio of the driving horse-power to air horse-power in the measuring section.

Since a considerable proportion of the jet kinetic energy is reconverted into pressure energy and thus returned to the blower, the above ratio is generally less than unity and can be as low as one-third.

Taking this figure, the power consumption of any tunnel can be given as

$$\rho v^3 F \ (6 \times 75) \text{ b.h.p.},$$

where F = cross section of jet in m.^{2}.
ρ = density of air in kg. sec.^{2}/m.^{4}.
v = air speed in m./sec.

At constant speed, the b.h.p. thus varies directly as the area of the jet and ranges from 300 b.h.p. for 7 m.^{2} (normal research type) to 2,000 b.h.p.

(R.A.E. 24-foot channel = 42 m.^{2})
4,500 b.h.p. (Chalais-Meudon = 100 m.^{2})
and 6,000 b.h.p. (N.A.C.A. full-scale = 150 m.^{2}).

The article gives an interesting account of air vibrations in tunnels and the method of cure (spoilers in nozzle and slots in receiver or tunnel).

The amount of turbulence in the tunnel air affects the measurements in certain cases and the method of detection and correction is explained (Twenty-six references.)

The Lift and Minimum Induced Drag of a Wing in the Neighbourhood of the Ground. (P. de Haller, Proceedings of Institute of Aerodynamics, Zurich, No. 4-5.) (2896 Switzerland.)

The theoretical investigation shows that the ground effect is complex.

In the case of a thin profile of infinite span, at angles of incidence greater than 15-16°, the presence of the ground diminishes the lift. If the angle of incidence exceeds 15°, the lift at first diminishes and then increases as the wing approaches the ground. The effect is less marked in the case of large wing curvature.

In the case of finite span, the ground effect reduces the induced drag and the effective angle of incidence is thus altered. There is a tendency for the lift to concentrate near the centre of the wing. In practice, the utilisation of a wing is limited by breakaway of flow on the suction side.

The effect of this on the problem can only be determined experimentally. (Nine references.)

Pressure Drop in a Pipe with Geometric Roughness. (L. Schiller, Forschung, Vol. 7, No. 3, May-June, 1936, pp. 154-155.) (1926 Germany.)

After a general review of the problem, special attention is given to the work of V. Streeter (frictional resistance) in artificially roughened pipes (Proc. American Soc. Civil Eng., Vol. 61, 1935, p. 163). This author investigated the effect of screw threads of same depth, but various shapes and pitches. Of interest is a determination of the size of sand grains yielding the same resistance coefficient as the screw thread. In the case of the threads 0.6 mm. deep, the equivalent grain has a diameter of 2.5 mm., whilst for very shallow threads (0.13 mm.) the equivalent grain is only 0.04 mm. It is probable that in the case of shallow threads, the flow is still in a critical stage and the quadratic law not fully established.

Engine Nacelles and Propellers and Airplane Performances. (D. H. Wood, J.S.A.E., Vol. 38, No. 4, April, 1936, pp. 148-160.) (1172 U.S.A.)

This article is a review of some 15 reports, mainly N.A.C.A.

Part I deals in detail with cowled radial air-cooled engines placed in various positions relative to the wing. Part II considers the case of the liquid-cooled engine, whilst some other possibilities are dealt with briefly in Part III.

Part I.—In estimating the relative order of merit of various nacelle-propeller-aeroplane combinations the following factors are utilised:—

(*a*) Propulsion efficiency.
(*b*) Nacelle drag factor.
(*c*) Net nacelle-propeller efficiency $= a - b$.

(*a*) This is defined as the proportion of total engine b.h.p. available for overcoming the drag of the aircraft without nacelles, after allowance for increased drag due to propeller slipstream has been made.

The propeller losses $(1 - a)$ thus include this extra drag. At a given speed (*a*) depends on V/nD, pitch angle, type and position of nacelle as well as on the speed factor $C = (\rho V^5/Pn^2)$, where

ρ = density, V = speed, n = r.p.m. and P = b.h.p.

(*b*) This is defined as proportion of total engine b.h.p. required to overcome nacelle drag, including interference drag, but excluding slipstream effects.

For radial engine installations the best position of the cowled nacelle is ahead of the leading edge of the wing, the fairing terminating at approximately one-half the wing chord.

Denoting such a nacelle position as A, the following table gives the improvement in factors *a*, *b* and *c*, compared with an uncowled nacelle placed below the

wing (position B). Case C in the table refers to an obsolete type of aircraft with nacelle in B position and gives a measure of the total improvement over the last seven years.

	A	B	C
(*a*) Propulsion efficiency	84%	80%	74%
(*b*) Nacelle drag factor...	13%	39%	28%
(*c*) Net nacelle-propeller efficiency ...	71%	41%	46%
Speed (m.p.h.)	194	156	128

It will be noticed that improved cowling and better location of nacelle relative to rest of aeroplane has resulted in a 25-30 per cent. gain in effective b.h.p., the corresponding gain in speed depending on the type of aircraft.

On the assumption that the nacelle drag varies as (engine diameter)^2, the factor (*c*) can be obtained on a speed basis for a series of engines of different diameter, power and operating speeds. Obviously, the smallest diameter engine giving the requisite power is best suited for high speed work (multi-row radial). At the present moment small diameter is usually associated with small power output and a multiplicity of such engines, although individually of small drag, are unable to propel a machine at high speed unless the propeller characteristics are favourable. This can only be achieved by the use of either variable gear or variable pitch airscrew, which thus assume special importance in this case.

In the reports so far published no reference is made to in-line engines. Experience with these has so far been mainly limited to small power outputs, and according to the author there is no evidence that such engines can be more efficiently cowled than radials of equivalent power. In the case of large power units, the available evidence definitely points to increasing cowling and cooling difficulties in the in-line engine compared to the corresponding radial.

PART II.—The highest power output in a single unit has so far been achieved by a boosted liquid-cooled engine. All the difficulties in this design are here concentrated on the radiators (engine and oil). At 200 m.p.h. the combined nacelle-radiator drag of the best Prestone cooled installations is of the order of 12-15 per cent. of the total drag. This is practically the same figure as for air-cooled radials.

It appears probable that the radiator drag can be reduced by cowling (see Abstract No. 39/58). No figures are, however, available. It is essential that such experiments reproduce inflow conditions as existing in practice. Departure from this has rendered most of the past experimental work useless.

PART III.—If the engine could be housed entirely within the wing, the need for a separate nacelle would not arise. The need of extension shafts together with the possibility of dangerous resonance vibrations between wing and shaft supports has, however, to be considered.

Experiments of the author show that the following wing-propeller efficiencies can be realised in the case of a pusher propeller.

Forward speed (m.p.h.)	Propulsion efficiency (engine inside wing)	Nacelle/propeller efficiency (best radial installation)
180	90%	78%
240	85%	71%
300	75%	55%

The differences in favour of engine installed inside the wing are thus very marked at high speeds, provided that there is no additional drag due to radiators.

An obvious solution is the skin radiator, which has been used already in some racing machines. It is hoped that work will concentrate on this design so as to improve its reliability.

Eleventh Annual Aircraft Research Conference. (M. Watter, Aero Digest., Vol. 28, No. 6, June, 1936, pp. 48-50 and 84.) (1725 U.S.A.)

Points of interest :—

1. A new high speed wind tunnel has been constructed for the N.A.C.A. at Langley Field, 8 feet diameter working section, maximum speed 500 m.p.h. produced by 8,000 b.h.p. electric motor driving 16 feet diameter 18-bladed fan propeller.
2. Deleterious effects of rivet heads on surface friction. Possibility of improved take-off performance of flying boats by suppression of exposed rivet on submerged part of hull.
3. New N.A.C.A. cowl incorporating spinner and guided air escape.
4. Renewed interest is shown in hydro-vanes as a means of improving the later stages of " unsticking."
5. Premature tip-stall of tapered wings can be prevented by increase of camber towards the top.
6. For air-cooled engine cylinders, a fin spacing of 12 per inch is recommended for the standard fin of $\frac{1}{4}$ inch depth.
7. Single cylinder Diesel engine, 5-inch bore, 6-inch stroke, 2,000 r.p.m., 200lb. per square inch break mean effective pressure at 10lb. square inch boost was demonstrated.
8. The external airfoil is considered the best take-off (high lift) device, since drag increase is small compared to split flap.

A Mathematical Contribution to the Theory of Vibration in Wings. (V. Borbely, Z.A.M.M., Vol. 16, No. 1, Feb., 1936, pp. 1-4.) (1729 Germany.)

Four integrals that appear in the theory of vibrating wings are evaluated in finite form by means of Bessel functions.

Wind Tunnel Investigation of Ordinary and Split Flaps on Airfoils of Different Profile. (C. J. Wenzinger, N.A.C.A. Report No. 554, 1936.) (1740 U.S.A.)

Conclusions :—

1. Full-span split flaps produced somewhat greater increases in $C_{L\,max}$ of the three airfoils tested than did full-span ordinary flaps of the same width, but the L/D at $C_{L\,max}$ was practically the same for the two types of flap.
2. Based principally on the speed-range ratio $C_{L\,max}/C_{D\,min}$, the relative order of merit of the airfoils tested with either ordinary or split flaps is N.A.C.A. 23,012, Clark Y, and N.A.C.A. 23,021.
3. Any gap between the wing and the leading edge of ordinary flaps had a very detrimental effect on the $C_{L\,max}$ attainable.
4. The hinge moment coefficients of the full-span ordinary flaps were practically independent of flap chord; the actual hinge moments varied approximately as the square of the flap chord. Both of these findings accord with theory.
5. The hinge moment coefficients of the full-span ordinary flap were practically the same as those of split flaps of similar size.

Wind Tunnel Tests of the " Pou du Ciel." (Les Ailes, No. 783, 18/6/36, p. 11.) (1748 France.)

A model (size not stated) was tested in the Amsterdam wind tunnel. Comparison with similar tests carried out at Lodz (see Translation No. 306) and Issy Les Moulineaux shows that the stability (especially at small angles of incidence—high speed) is largely controlled by the percentage overlap between the two wings. Thus at Lodz, with a 3 per cent. overlap, the stability is satisfactory at 3° incidence. The Dutch tests (overlap 13.8 per cent.) show insufficient stability at 6° and definite instability at 3°. The wings had the same angle of incidence and the effect of gap has not so far been investigated.

Attention should be called to the fact that in these model tests the controls are rigidly held.

Causes of Accidents. (E. L. Vidal, Inter Avia., No. 331, 11/6/36, pp. 1-3.) (1784 Switzerland.)

In U.S.A. aircraft passenger traffic the percentage of accidents is almost equally divided between error of judgment, power plant failure, structural failure, atmospheric influence and causes unspecified.

In the case of mail freight over one half of the accidents are due to errors of judgment, whilst nearly 30 per cent. are due to power plant failures. The total number of accidents have decreased from 115 (in 1932) to 62 (in 1935). "According to the law of averages, a passenger could fly on American air lines 500 miles a day for 20 years without fatal injury. To-day he can fly 500 miles a day for 120 years."

Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. (C. H. Zimmerman, N.A.C.A. Report No. 557, 1936.) (2736 U.S.A.)

Typical models and the testing technique used in the N.A.C.A. free-spinning wind tunnel are described in detail. The results of tests of two models afford a comparison between the spinning characteristics of scale models in the tunnel and of the airplanes that they represent.

The models are built of balsa wood and ballasted with lead to the proper mass distribution. A clockwork delayed action mechanism is mounted in the model to move the control surfaces during the spin.

The models of the XN2Y—1 and F4B—2 airplanes gave good approximations to the spinning characteristics of the airplanes, in both steady spins and recoveries. Since these models were scaled from somewhat similar biplanes, no conclusions are drawn as to the reliability of model results in general.

The Conquest of the Stratosphere (concluding article). (R. Bernson, Rev. de l'Arm. de l'Air, No. 85, Aug., 1936, pp. 888-916. For Part I, see No. 84, July, 1936, pp. 773-794.) (2882 France.)

A detailed description of the ascent of the American balloon Explorer II (Nov., 1935) where the record height of 21,700 m. was reached.

The stratosphere balloon as designed at present was subjected to considerable stress concentration when only partly filled (ascending or descending). Suggestions by Prof. Picard and the U.S.S.R. Government concerning necessary modifications in order to reach greater heights are discussed.

The article is well illustrated.

Rate of Climb and Steepness of Flying Path. (C. Alippi, L'Aerotecnica, Vol. 16, No. 7, July, 1936, pp. 538-542.) (2844 Italy.)

The path of an aircraft for the quickest climb (highest rate of ascent) does not coincide with that for the steepest climb.

The former corresponds to an angle of incidence making $(Cw/Ca)^{1.5}$ a minimum.

The steepest climb has a slightly greater angle of incidence approximately half way between Ca max. and $(Cw/Ca)^{1.5}$ min.

This angle of incidence does not only depend on aerodynamic constants but also on the size of the aircraft and especially on the excess power available.

Flight on Rotating Wings. (W. L. Le Page, J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, pp. 255-288.) (2885 U.S.A.)

The historical section of this article is of interest in showing photographs of various helicopters in flight. With regard to the "direct control" autogiro, the view is expressed that the suppression of the fixed control surfaces has reduced aerodynamic efficiency. In spite of the undoubted success of the autogiro (including the latest development in jumping starts), the author is of the opinion

that there exists a demand for the true helicopter. The principal causes of previous failures of this type of machine are classified as:—

(1) Failure to balance rotor torque.
(2) Excessive rotor disc loading.
(3) Inefficient utilisation of power.
(4) Mechanical complexity.
(5) Excessive weight and parasite drag.
(6) Gyroscopic precession in the rotor system.
(7) Instability and ineffective control.

Some of these are treated in detail. (To be continued.)

Parachutes with Variable Rates of Descent. (Flugsport, Vol. 28, No. 14, p. 347, and Inter Avia., No. 319, 30/4/36, p. 4.) (2892 U.S.S.R., France.)

RUSSIAN EXPERIMENTS.—A valve operated by the pilot changes velocity of descent between 4 and 30 m./sec.

FRENCH EXPERIMENTS.—The parachute known as the " Magnet " has no valve but is fitted with an annular sail along the rim. By means of an arrangement of ropes, the pilot can control the effective drag of the chute and thus the rate of descent.

Experimental Investigation on Wing Flutter. (H. L. Studer, Proceedings of Institute of Aerodynamics, Zurich, No. 4/5.) (2897 Switzerland.)

The model wings 40 cm. span and 12 cm. chord were made of balsa wood (reinforced) and mounted so that they could execute torsional and transverse vibrations simultaneously. The most dangerous type of flutter is associated with a periodic variation in the type of air flow round the wing (so-called hysteresis effect of the stall).

If such vibrations start during a steep dive, the angle of incidence of the wing should be increased quickly and then slowly diminished. It is preferable not to proceed from a horizontal flight into a dive directly, but go through a so-called " tonneau " manœuvre first.

It has been observed in several cases where flutter developed and ultimately lead to a fatal accident that the pilot made no effort to save himself by parachute and did not even switch off the engine.

According to the author large amplitude vibrations of the type considered are likely to cause the pilot to lose consciousness in a short time.

Forty-one references.

Propulsion by Reaction without Utilisation of External Air. (N. A. Rinin, L'Aerotecnica, Vol. 15, No. 9-10, Sept.-Oct., 1935, pp. 912-914.) (333 Italy.)

Three kinds of rockets are considered:—

(1) Normal rocket, the thrust being obtained by the expulsion of products of combustion of the charge.
(2) Rockets which aspirate the external air in order to increase the thrust.
(3) Rockets which capture the external air in order to increase the combustion.

The thrust of (1) is given by $F = (u/g)\,c$,

where u = weight of gas expelled per second.
c = velocity of expulsion.

In order to obtain a large thrust, u and c must be large.

Methods for increasing u and c (type 3).

If c' = velocity of expulsion.
a = additional mass of air captured in relation to products of combustion.

The propulsion efficiency η' is given by

$$\eta' = (2\,vc' - v + v/a)/(c'^2 - v^2 + 2\,v^2/a).$$

If $a = 1$, this reduces to the efficiency of the simple rocket

$$\eta = (2v/c)/(1 + v^2/c).$$

This becomes a maximum ($= 1$) if $v = c$.

In the case of added air, it is necessary to obtain a relation between c and c'.

If all the thermal energy is transformed into kinetic energy

$$c'_1 = 91\sqrt{\{Q/(1 + aL)\}}$$

when Q = calorific value.

L = necessary weight of oxygen.

a = excess coefficient.

If oxygen supplied pure, $a = 1$.

In the case of air $a = 4.33$.

The author considers the combustion of various hydrocarbons, either pure or mixed with metallic powders (Li, Bo, Al, etc.).

Maximum velocity is obtained with H_2 (5,170 m./sec.).

Good results have been obtained with a mixture of petrol and oxygen in the ratio of 1 : 3.5 by weight.

From the ideal velocity of expulsion, the author next passes to the practical case, where a portion only of the heat of combustion becomes available (thermal efficiency of cycle). This depends primarily on the expansion ratio.

If p_o = pressure before final orifice in combustion chamber.

p = back pressure.

$$\eta t = 1 - (p/p_o)^{(k-1)/k}$$

p is not necessarily $= p_a$, the atmospheric pressure.

The exact solution is difficult, but some attempt has been made following the methods of Professor Macinski.

The general theory of rocket flight is next considered. Simplifying assumptions (constant air density, constant resistance coefficients, constant rate of discharge) have to be made and the author refers to a number of published works.

It is finally concluded that for great heights (30 km.) and high speeds (800 m./sec.) rocket propulsion is the only solution.

Radial Engines Manufactured by Gnome-Rhone (France). The K.14 and NO-14. (Les Ailes, No. 783, 18/6/36, p. 4.) (1750 France.)

According to statements by the firm, approximately 2,000 K.14 engines are in daily service. It is admitted that as a result of inadequate cooling, fairly frequent decarbonisation is required. This depends on the types of cowling fitted. The old type of cowling as fitted to the Bloch and Amiot are unsatisfactory (decarbonisation time 70 hours). Savoia-Marchetti have developed a satisfactory cowling for this type of engine and similar designs are now being fitted to the Potez PZL, Loire 46 and Amiot (overhaul time extended to 200 hours).

American type, controlled pressure cowling is now being tried on the Bloch 200. As a result of experience gained (60,000 flying hours), a new (1937) K.14 has been brought out, known as NO-14. The cooling fin area has been increased from 18 to 25 dm.^{2} per litre of stroke volume and more fins have been fitted to the cylinder base. The cylinder is nitrated and sodium-cooled valves are fitted. The supercharger drive has been strengthened so as to enable greater boost pressure.

The new NO-14 will be rated at 950 b.h.p. at 4,000 metres. It is stated that ultimately all the 2,000 K.14 in service will be renovated to conform to NO-14 specifications, at a cost of 90,000 francs per engine. The author quotes French Press opinions questioning the policy of designing air-cooled radials of the two-bank type of such large power output and thinks that the alternative water-cooled design required further study.

Stroboscope for Synchronising Engine. Revolutions in Multi-Engine Aircraft. (Aviation, Vol. 35, No. 6, June, 1936, p. 45.) (1760 U.S.A.)

Inside a casing is a disc driven by the central engine. This disc is illuminated by two neon lamps actuated by the ignition system of the two engines. The disc is fitted with a number of radial marks depending on type of engines and by regulating the speed of the two outboard engines till the disc appears stationary, all three engines can be synchronised.

Boosted Performance of a Compression-Ignition Engine with a Displacer Piston. (C. S. Moore and H. H. Foster, N.A.C.A. Tech. Note No. 569, May, 1936.) (1869 U.S.A.)

The engine operation under boosted conditions was very smooth, there being no combustion shock even at the highest maximum cylinder pressure (1,150 pounds). Indicated mean effective pressures of 240 pounds per square inch for fuel consumptions of 0.39 pounds per horse-power-hour have been readily reproduced during routine testing at 2,000 r.p.m. at a boost pressure of 20 inches of mercury.

Measurement of Gas Temperatures in an Internal Combustion Engine. (A. E. Hershey, Sci. Absts. (Section B), Vol. 39, No. 462, 29/6/36, p. 349. A.S.M.E., Trans. 58, pp. 195-201, April, 1936.) (1900 Great Britain.)

A summary is given of the various methods used in determining gas temperatures in an internal combustion engine, with references to the various papers and reports published on the subject. Three general methods are briefly described, but the major part of the paper is devoted to a description of the experiments carried out at the University of Illinois. These form the basis of calculation of temperatures from radiation emission and absorption measurements, and include the measurement of temperatures by spectral line reversal; the latter is regarded as the only reliable method devised for this purpose. Sectional drawings of the apparatus are included and the results are given in the form of curves, a comparison being made with the calculated values of other workers, and possible reasons are given for discrepancies.

Further Studies of Flame Movement and Pressure Development in an Engine Cylinder. (C. F. Marvin, Jnr., N.A.C.A. Report No. 556, 1936.) (2055 U.S.A.)

The flame movement was traced by stroboscope examination of 30 small windows placed in the combustion head of an L head engine. Various heads were tried, the average compression ratio being 5/1, the bore and stroke of the engine was $3\frac{3}{4}$ inches and 4 inches respectively, the speed of operation varying between 600 and 1,000 r.p.m. Motor benzol was used as fuel, the mixture generally being that giving maximum power. Of interest is the uniform spread of the flame, showing predominance of small scale turbulence and absence of pronounced swirl.

The photographs show that flame speed and rate of pressure rise increase nearly as fast as engine speed, *i.e.*, complete inflammation keeps pace with position of maximum pressure as obtained from the indicator diagram.

The shortest combustion times and most rapid use of pressure are obtained by using multiple spark plugs.

Distribution of Heat Loss to the Jackets in an Internal Combustion Engine Cylinder. (C. F. Taylor, J. Aer. Sci., Vol. 3, No. 8, June, 1936, pp. 282-286.) (2058 U.S.A.)

Tests were carried out on a single cylinder water-cooled Liberty A2 aero engine.

Separate cooling was applied to the jacket, head and exhaust valve passage. The measurements included power output, fuel consumption, cooling water quantity and temperature and spark setting.

The effect of mixture strength, compression ratio, ignition advance and engine speed on the heat transmission was investigated.

The following represents an average distribution of heat loss:—

Cylinder head ...	...	...	50 per cent.
Cylinder jacket ...	...	...	30 ,,
Exhaust valve passage		...	20 ,,

Ducted Radiators. (F. W. Meredith, Airc. Eng., Vol. 8, No. 90, August, 1936, pp. 213-217.) (2338 Great Britain.)

In a freely exposed radiator, the induction efficiency is of the order of 0.5. Considering the radiator as an actuator disc, the velocity through the disc is thus 0.6 of the velocity of the stream in which it is exposed. In the case of a ducted radiator, the induction efficiency (=duct efficiency) is generally above 0.9. The power expended in drag is thus only about two-thirds of the power expended with the same radiator freely exposed at the speed at which it would provide the required cooling.

It is assumed in this investigation that there exists parallel flow at the duct exit and that the issuing stream does not disturb the flow of the external stream.

Provided exit conditions are adjusted to suit speed of aircraft, there is thus no need for an increase in cooling power with forward speed.

Further, the combined effect of compressibility and heat transfer may reduce this power consumption for cooling to zero, provided the radiator is of sufficient cross-section. If the engine exhaust heat is added near the duct exit, the combination may even result in a net gain in power, estimated at 5 per cent. for an aircraft speed of 300 m.p.h. (velocity through radiator 100 m.p.h.). Further experimental data on length and diameter of tubes in ducted radiators are required before this can be investigated further.

Survey of the Causes of Power Plant Failures—Air Line and Private Planes. (U.S. Bureau of Air Commerce Report.) (Inter Avia., No. 350, 3/8/35, pp. 1-3.) (2567 U.S.A.)

The analysis classifies failures according to three major groups: Engine proper, engine installation and airscrew. The average percentages over the five-year period 1931-1935 are 60, 30 and 10 per cent. respectively.

There is a tendency for the percentage engine failure increasing, as installation and propeller become more reliable.

The most vulnerable point of the engine is the alloy head—next come exhaust valves and spark plugs (effect of leaded fuels).

Half the installation troubles are due to the fuel system.

Airscrew reduction gears are now almost faultless.

Ignition Process in Diesel Engines. (W. Wentzel, Forschung auf dem Gebiete des Ingenieurwesens, Vol. 6, No. 3, May-June, 1935. Translation N.A.C.A. Tech. Memo. No. 797, June, 1936.) (2633 Germany.)

The writer analyses the heating and vaporisation process of fuel droplets in a compression ignition engine on the basis of the theory of similitude and concludes that the required period for heating and complete vaporisation of the average size fuel drop is only a fraction of the actually observed ignition lag. The result is that ignition takes place in the fuel vapour-air mixture rather than on the surface of the drop. The theoretical result is in accord with the experimental observations by Rothrock and Waldron (see Abstract No. 39/62). The combustion shock occurring at lower terminal compression temperature, especially in the combustion of coal tar oil, is attributed to the simultaneous ignition of a larger fuel vapour volume formed prior to ignition.

Blower Cooling of Radial Engines (based on N.A.C.A. Tech. Note No. 572). (Autom. Ind., Vol. 75, No. 9, 29/8/36, pp. 281 and 291.) (2716 U.S.A.)

From the results of these tests the following conclusions were drawn :—

(1) The minimum power required for satisfactory cooling with an over-all blower efficiency of 100 per cent. varied from 2 to 6 per cent. of the engine power depending on the operating conditions.

(2) The shape of the jacket had a large effect on the cylinder temperatures. Increasing the air speed over the front of the cylinder by keeping the greater part of the circumference of the cylinder covered by the jacket reduced the temperatures over the entire cylinder.

(3) The temperature difference between the cylinder and the cooling air varied inversely as the 0.4 to 0.6 power of the cooling air weight, depending on the location of the thermo-couple; those on the barrel varied as the higher power of the air flow.

(4) The total head drop across the cylinder varied as the 1.77-2.04 power of the cooling-air weight, depending on the cylinder and jacket combination. The power required for cooling varied as the 2.81 power of the cooling-air weight for three of the cylinder and jacket combinations and as the 2.90 power for the fourth combination.

(5) An air quantity of 1.09lb. per sec., properly directed and kept in contact with the cylinder, would satisfactorily cool the Wasp H cylinder, when it was developing 45 b.h.p., maximum temperature being 475°F.

Effect of Nozzle Design on Fuel Spray and Flame Formation in a High-Speed Compression-Ignition Engine. (A. M. Rothrock and C. D. Waldron, N.A.C.A. Report No. 561, 1936.) (2798 U.S.A.)

Fuel was injected from different types of injection nozzles into the combustion chamber of the N.A.C.A. combustion apparatus, operated as a compression ignition engine; high speed motion pictures were taken at the rate of 2,200 frames per second of the fuel sprays and the combustion.

The photographs indicate that the rate of vapour diffusion from the spray is comparatively slow and that this slow rate of diffusion for combustion chambers with little or no air flow prevents the compression ignition engine, with the present methods of fuel injection, from giving the high performance inherent in the compression ratios. It is concluded that high performance cannot be realised until the methods of distributing the fuel are improved by means of the injection nozzle design, air flow, or both (see also Abstract No. 39/60).

Exhaust Gas Analysis During Flight. (Les Ailes, No. 791, 24/9/36, pp. 5-6.) (2864 France.)

The well known Dorsat apparatus has been simplified by using vessels made of rubber for the reagents. In this way the gas can be introduced by mere hand pressure and the troublesome adjustable reservoir is avoided.

The apparatus is contained in a metal frame suspended on rubber cords. It is stated that flight tests have shown that the mixture strength is generally too rich and that economies up to 30 per cent. in fuel consumption should be possible without affecting engine temperature detrimentally.

German Progress in Oil-Driven Aircraft. (Les Ailes, No. 791, 24/9/36, p. 3.) (2865 Germany.)

During 1935 at least ten German transport machines, fitted with oil engines, carried out regular flights, covering over one million miles between them. It is reckoned that this year the mileage will be at least doubled.

The Junkers firm are said to produce 200 engines a month, and according to the French author 10 per cent. of the German heavy bombers are fitted with Diesel engines.

The Junkers firm are producing a new engine rated at 1,200 b.h.p. Eight of these engines driving four propellers are destined for the new DO 20 flying boat under construction.

Experiments on the Friction and Leakage of Piston Rings. (M. Eweis, Forschungsheft, No. 371, March-April, 1935.) (2895 Germany.)

The author obtains an expression for the friction force of a piston ring, using the fundamental equation of laminar viscous flow and assuming that the variation in thickness of the oil film is limited to a small region in the neighbourhood of the rounded edge of the ring.

He next investigates the question of leakage, on the assumption that the ring never leaves the seat furthest away from the piston crown. (This assumption appears justified for the experimental condition subsequently employed, in which the ring inertia is unable to overcome the combined effect of gas pressure and friction.)

The theoretical figures for leakage and friction were subsequently tested by an experimental ring in which the piston and rings are stationary whilst the cylinder wall is reciprocated. The top ring is subjected to a variable gas pressure supplied by a compressor, the pressure variation at this ring as well as the gas pressure behind the other rings being recorded by a Farnborough electrical indicator. The frictional force on the piston is recorded piezo-electrically.

It appears that the variation in gas pressure behind the rings followed theory, and is rapidly damped out as the number of rings increase. The conditions of experiment were such that a proper oil film was not generally established between ring and cylinder (piston speed insufficient).

The friction was thus mainly of the boundary type and increased linearly with gas load, whilst diminishing with increase of speed.

From the theoretical investigation detailed in the beginning of the report (fluid friction), the friction should increase as $v^{\frac{1}{2}}/p^{\frac{3}{2}}$, when v = piston speed and $p = f$ (gas pressure).

Defence of Heavy Bombers Against Enemy Aircraft. (K. L. Wassiliew, Luftwehr, Vol. 3, No. 3, March, 1936, pp. 118-122.) (1384 Germany.)

The article deals primarily with the preparation for and execution of long distance bombing raids.

PREPARATION.—In order to safeguard machines as far as possible from enemy attack, whilst still on the ground, the bombers should be distributed over a wide area and only concentrated into groups near the frontier when ready to undertake the raid.

To render this concentration reasonably safe, effective reconnaissance is essential.

Direct protection to the assembled bombers may be afforded by fighting squadrons stationed along probable lines of enemy approach, or a diversion may be created by light bombing raids. If, in spite of all, the enemy approaches too closely to the point of intended concentration the heavy bombers must be disbanded towards the rear. To ensure such mobility is the object of peace time training.

EXECUTION.—Heavy bombers should only be used against targets of importance. The necessary defence ties down large enemy forces and decisive actions may result.

Air engagements resemble fleet action in so far as finality should be the principal aim and it is, therefore, useless to carry out attacks of this kind without ample reserves.

For mutual assistance, bombers should operate in groups. A certain percentage of each group (up to 33 per cent.), instead of carrying bombs, are provided with armour and heavy guns. These are placed on the outside of the formation to supplement the machine gun fire of the bombers proper.

When crossing the frontier and till the vicinity of the objective is reached, groups should not exceed 15 individual machines. This gives sufficient mutual protection without sacrificing mobility and betraying objective. In order to concentrate bombing damage 2-3 of such groups combine in an attack, but split up after release of bombs. Fresh groups carry on as they arrive, the engagement being continuous as long as reserves last.

Co-operation of Anti-Aircraft Artillery and Fighting Aircraft in Defence Against Bombers. (C. L. Chenault, from Coast Artillery Journal, Nov.-Dec., 1935. Luftwehr, Vol. 3, No. 3, March, 1936, pp. 127-131.) (1385 U.S.A.)

Co-operation between anti-aircraft artillery and aircraft is only possible at night if sufficient illumination is provided by means of searchlights.

During the late war efficient co-operation of these types was only provided in 1918 (151 squadrons at Abbeville).

Reference is made to some recent experiments in U.S.A. (Maxwell Field, 1934). In these the bomber operated at relatively low altitudes (12,000 feet). It was found that the various units co-operating in the defence (such as alarm post, sound ranging, battery and fighters) could be controlled by a single authority.

Interception of the bomber can apparently be assured if not less than 40 miles of territory has to be flown over by the bomber before it can attack its objective.

This territory has to be provided with a sufficient number of searchlights (15 on a front of 50 miles).

If general protection has to be provided, defence is very much more expensive than attack. Usually the line of approach of the enemy can, however, be predicted before he sets off and this simplifies the problem.

If the attack is carried out at great altitudes the bombing searchlights can no longer co-operate.

In forcing the enemy to fly high, searchlight will, however, achieve some useful purpose, besides helping to identify friend from foe should the fighting continue to lower altitudes.

Defence of Aerodromes Against Air Attack. (Poplawski, from W.P.O. (U.S.S.R.), Dec., 1935. Luftwehr, Vol. 3, No. 3, March, 1936, p. 133.) (2198 U.S.S.R.)

The danger of enemy attack is greatest when own aircraft are either getting ready to take-off or have just landed.

The enemy presumably will attack at low altitude so as to reduce danger from anti-aircraft batteries.

The defence measures consist of :—

1. Warning of raid.

   The aerodrome must be linked up with the general system and if possible have its own warning organisation.

   Own aircraft may only approach aerodrome at fixed heights and in a given direction. Possible provision of balloon curtain and artificial fog.
2. Provision of sufficient machine guns on the ground. Own aircraft should be parked so that its machine guns are available.

   Ground personnel supplied with quick-firing rifles.
3. Distribution of fuel and munition stores into small units.
4. Underground shelters.
5. Ground organisation to deal with clearing debris after raid.
6. Training of personnel and especially determining responsibility of various heads (officers in charge of flight, station, batteries, signals).

The Use of Captive Balloons in Aerial Defence. (J. Lucas, Rev. de l'Arm. de l'Air, No. 85, Aug., 1936, pp. 863-867.) (2881 France.)

Various types of net defences used by the German, French, English and Italian Governments in the last war are described.

Two instances where German machines were caught in the nets are described.

The presence of 120 balloons on the outskirts of Paris is held to have forced German raiders to alter line of approach, whilst the immunity of Venice from Austrian air attack is considered to be due to the very efficient Italian balloon defence. The expense of such a scheme is held to be commensurable with the value of the targets.

Balloon curtains can be operated by a relatively small staff requiring no expensive instruments or training and the method compares favourably with anti-aircraft gunnery.

Modern developments have raised the possible ceiling of balloon curtains from 4,000 m. (highest Italian) to 7,000 m. The mere suspected presence of such curtains has a valuable psychological effect.

French Military Aircraft. (Aero Digest, Vol. 29, No. 2, Aug., 1936, pp. 34-36 and 58, and No. 3, Sept., 1936, pp. 28-31.) (2752/2420 U.S.A.)

A brief review of the present position.

Part I deals with fighters (single and two-seat) and light bombers (multi-seat).

Part II considers heavy bombers, reconnaissance and seaplanes, as well as a list of civil aircraft readily convertible for military use.

The article is copiously illustrated.

The following are estimated numbers:—

Fighters	1,400
Bombers	900
Reconnaissance	600
Seaplanes	600

Over a third of these are stated to be obsolete.

Prices of American Fighting Aircraft. (Luftwissen, Vol. 3, No. 8, August, 1936, p. 215.) (2899 U.S.A.)

The following tenders were received by the U.S.A. Government for the supply of a modern single-seater fighter to Air Corps specification:—

No. in Series	Price per Aircraft	Firm
25	29,412 dollars.	Curtiss.
200	14,150 ,,	
25	34,148 ,,	Chance Vought.
200	16,051 ,,	
25	44,000 ,,	Consolidated Aircraft.
200	24,260 ,,	

Technical Production of Acetylene. (H. P. A. Groll and J. Burgin (Shell Development Co.), Can. 353,604, Oct. 15. Chem. Absts., Vol. 30, No. 5, 10/3/36, p. 1543.) (1041 U.S.A.)

A gaseous mixture of a hydrocarbon and oxygen is subjected to incomplete combustion in an enclosed apparatus at a linear gas velocity not greater than the flame velocity of the mixture. The linear gas velocity is subsequently increased to exceed the flame velocity throughout at least the greater part of the flame, while combustion is maintained by part of the flame proper.

Liquid Fuels for Diesel Engines. (British Patent No. 432,592. Chem. Absts., Vol. 30, No. 2, 20/1/36, p. 597.) (1043 U.S.A.)

The fuel consists primarily of a hydrocarbon to which 0.1 to 5 per cent. of true esters (other than lactide or lactone) are added.

These esters must have a boiling point above 150°C. and a suitable example is the hexyl ester obtained from the oxidation of wax.

Mechanism of the Oxidation of Petroleum Hydrocarbons. (A. K. Plisov, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3975.) (1793 U.S.A.)

Air was passed through 100 gm. of the hydrocarbon at the rate of 200 litres/hour, the temperature being 120° and 150°C. respectively, both with and without catalysts. In the former case, the quantity of peroxide formed diminished progressively with time and none could be detected after four hours. In the absence of catalysts, the peroxide content at first increases to a maximum and subsequently decreases to a lower constant value. The amount of acid formed, on the other hand, is unaffected by the catalysts and increases continuously with time of experiments.

Production of Acetylene from Petroleum according to the Method of the Firm "l'Air Liquid." (S. Ya. Miloslavski and D. L. Glizmanenko, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3976.) (1794 U.S.A.)

Solar oil is cracked by an electric arc producing a gas rich in acetylene (35 per cent.).

The energy consumption is approximately 3.5 kw. hours per cubic metre of gas

Rating Aviation Fuels in Full-Scale Aircraft Engines. (C. B. Veal, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3988.) (1795 U.S.A.)

The relative order of merit of aircraft fuels depends on the severity of the conditions and the design of the engines. The present C.F.R. method for rating fuels will be retained for the present in want of anything better.

Use of Inhibitors in Gasoline. (C. D. Lowry, Jnr., Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3989.) (1796 U.S.A.)

The inhibitory value of certain substances such as phenol and amines, depends on the critical oxidation potential. Accelerated oxidation tests are a useful but by no means infallible guide as to the stability of fuels under commercial conditions.

Nature of the Octane Scale. (E. B. Evans and others, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3991.) (1797 U.S.A.)

As an alternative to the octane scale of rating fuels, a pressure scale is proposed. This is based on the limiting compression pressure above which knocking takes place. The new scale was satisfactorily extended to deal with fuels beyond the 100 octane scale.

Alteration of Lubricating Oils in Use and Their Regeneration. (H. Karaptner, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3994.) (1798 U.S.A.)

Fresh oil, used oil, filtered oil and regenerated oil were compared. Regeneration yields a product very similar to the original oil.

Eighty-five references.

Improved Lubricants and Lubrication. 1. *Fundamental Chemical and Physical Forces in Lubrication.* (G. L. Clark and others, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 3995.) (1799 U.S.A.)

X-ray investigation of adsorbed film of chlorinated esters of the fatty acids shows that the thickness of the orientated film may be comparable to that existing in bearings with viscous lubrication. Such orientated films are not readily disorganised by temperature rises and thus afford better protection against wear.

Testing Liquid Lubricants. (U.S. Patent No. 2,037,365. L. Cammen, Chem. Absts., Vol. 30, No. 11, 10/6/36, p. 4002.) (1801 U.S.A.)

The adsorption of the oil is measured by noting the loss of weight occurring as a disc wetted with the oil is gradually speeded up.

Motor Fuels. (E. V. Bereslavsky, Chem. and Ind., Vol. 55, No. 27, 3/7/36, p. 584. B.P. 444,026, 11/9/34; U.S., 24/1/34.) (1903 Great Britain.)

The fuel comprises a mixture of petrol (85 per cent.), anhyd Et OH (10 per cent.), and a sec. or tert. hydroaromatic alcohol, *e.g.*, terpineol, and/or an open chain unsaturated alcohol, *e.g.*, geraniol (5 per cent.). Steam-distilled pine oil, preferably treated with a gum inhibitor, may be used as the third constituent. It functions as a blending agent and also increases the calorific value and the anti-knock value of the mixed fuel.

Electron Diffraction Analysis of the Orientation of the Molecules of Lubricating Oils. (L. T. Andrew, Chem. Absts., Vol. 30, No. 12, 20/6/36, p. 4307. Trans. Faraday Soc. 32, 607-16, 1936.) (1914 U.S.A.)

The best boundary lubricants are those with maximum orientation and with little or no tendency to oxidise. The orientation test indicates the following arrangement of the oils tested in the order of diminishing quality: (1) Mineral oil with small percentage of fatty oil; (2) Russian, California and non-viscous Pennsylvania; and (3) Texas oil, poor owing to gumming.

There is no relation between viscosity and orientation.

Experiments on heating polished metal surfaces in oil at 250°C. indicate that metal corrosion by oil is due to an accumulation of an amorphous layer, probably of organic material.

The Explosion of Methane (Fire Damp) by the Filament of Electric Incandescent Lamps. (E. Cotté, Comp. Rend., Vol. 201, No. 27, 30/12/35, pp. 1484-1485.) (1939 France.)

Experiments were carried out using a 20 per cent. coal gas/air mixture. On puncturing the glass bulb with a file, explosions were obtained inside the bulb. These were not propagated to the outside, until the hole in the glass exceeded a certain minimum diameter (2 mm.). As the hole is further increased, the explosions (after passing through a maximum) become less certain and none is formed if the glass is removed entirely.

The flash produced by the burning of the filament (4-volt) will not ignite the gaseous mixture. Electric lamps in mines should therefore have bulbs of large diameter made of a brittle glass which collapses completely under shock.

Researches on Increasing the Sensitivity of Aviation Petrols to Lead Tetra Ethyl. (A. Feigin and V. V. Zeleniak, Aeron. Eng. (U.S.S.R.), No. 6, June, 1936, pp. 41-45. Available as Translation No. 334.) (1955 U.S.S.R.)

The experiments were carried out on the following six fuels (octane determination C.F.R., 900 r.p.m., mixture temperature 150°C.).

Name	Density	1st drop	Distillation °C. 10%	50%	90%	End part	Octane No.
Baku Standard Aviation	0.749	78	90	107	137	165	69
Baku No. 1	0.745	77	89	101	119	149	74.5
Baku No. 2	0.725	50	70	84	100	130	78
Grozny No. 1	0.668	27	36	68	149	165	69
Grozny No. 2	0.671	27	35	73	152	167	66
Grozny No. 3	—		Distils under 40°C.				80

The following table gives the lead response of some patent fuels and mixtures:—

Name	Octane No. With Pb (cc. per kg.)				
	0	.25	.50	1.0	1.5
Baku Standard	69	75	80	86	90
Grozny No. 1	69	79	85	89.5	91
Grozny No. 2	66	75	80	86.5	87.5
Grozny No. 3	80	—	92	—	—
90% Baku Standard + 10% Grozny No. 3	70	81	83.5	86.5	92
85% Baku Standard + 15% Grozny No. 2	69	79.5	82	87	—
80% Baku Standard + 20% Baku No. 2	—	—	82.5	88.6	90.6
94% Baku No. 1 + 6% Grozny No. 3 ...	74.5	81.5	85	90.5	91
90% Baku No. 1 + 10% Grozny No. 2 ...	73	83	85.5	89	91.5

Distillation Characteristics of Mixtures.

Name	Distillation °C. 1st drop	10%	50%	90%	End part	Density
90% Baku Standard + 10% Grozny No. 3	45°	74°	108°	139°	170°	0.733
85% Baku Standard + 15% Grozny No. 2	60°	77°	105°	138°	164°	0.736
80% Baku Standard	51°	78°	102°	136°	168°	0.743
94% Baku No. 1 + 6% Grozny No. 3 ...	46°	75°	102°	122°	140°	0.731
90% Baku No. 1 + 10% Grozny No. 2 ...	62°	80°	100°	136°	147°	0.744

From the above the following conclusions are drawn:—

(1) The high lead response of the Grozny petrols (for small addition of Pb).
(2) The improvement in the lead response of Baku standard by the addition of Grozny (for small additions of Pb).
(3) The improvement of Baku 1 over the Standard Baku.
(4) The cost of the additional equipment required to produce these low boiling petrols is insignificant compared with the economy and other advantages gained by reducing the amount of lead required.

In the case of Octane No. 85, this reduction amounts to 50 per cent., the original Baku Standard requiring 1 cc./kg. against 0.5 cc. for Baku No. 1/Grozny mixtures (see also Abstract No. 39/86).

N.B.—1 cc. of Pb/kg. corresponds approximately to 3.5 cc./gallon.

Treatment of Motor Fuels. (P. Poetschke, Chem. and Ind., Vol. 55, No. 29, 17/7/36, p. 630. U.S. Patent No. 2,018,570.) (1995 Great Britain.)

Anti-knock cartridges are made of a mixture of C_{10} H_8 and stearic acid (I), with or without a metal container, the interior being filled with a solid mixture of Pb Et_4 and (I). These cartridges are dissolved in the fuel as required.

Gasolines and Gasoline Fractions. Susceptibility to Tetra Ethyl Lead and Aniline. (C. O. Tongberg and others, Ind. and Eng. Chem. (Indust. Edn.), Vol. 28, No. 7, July, 1936, p. 792-794.) (2032 U.S.A.)

The lead response of different fractions of a petrol as measured in a series 30B ethyl knock-rating engine differ considerably. These differences are thought to be due to the presence of certain catalyst poisons such as sulphur compounds.

The increase in octane number due to the addition of aniline is practically linear for additions between 2 and 7 per cent.

When aniline and lead are used together, the results are additive.

Absorption of Air by Mineral Oils. (A. Gemant, Chem. Absts., Vol. 30, No. 13, 10/7/36, p. 4656.) (2087 U.S.A.)

The Bunsen coefficient for a series of oils varied from 0.073 to 0.106, decreasing with increase in oil viscosity. The absorption coefficient is practically indepen-

dent of temperatures between the limits of 15°C. and 80°C. This throws doubt on the theory that breakdown strength of oil varies proportionally to the air content of the oil.

Heat Conductivity and Specific Heat of Oils. (C. Lochmann, Chem. Absts., Vol. 30, No. 13, 10/7/36, p. 4656.) (2088 U.S.A.)

K = conductivity and C = specific heat.

Values given in the literature are summarised for liquid petroleum products K in (gm. cal./sec./cm.^{2}/°C./cm.) = $0.0002804 \times (1 - 0.00054\ t)/d$ and C in (gm. cal.^{d}/gm.) = $(0.4024 + 0.00081\ t)\ d^{\frac{1}{2}}$

when d = density at 15°C.

t = temperature °C.

The experimental results disprove the theory that petroleum asphalt is a supercooled liquid producing a latent heat exchange on solidification.

Anti-Knock Fuels. (Chem. Absts., Vol. 30, No. 13, 10/7/36, p. 4662. French Patent No. 793,967, 1936.) (2089 U.S.A.)

The use of mixtures of carboxylated fatty acids and amino compounds of all structures is claimed as an anti-knock agent. A mixture of Ph NH_2 and stearic acid or soaps of ethanolamines is also efficacious.

Lubricants. (Chem. Absts., Vol. 30, No. 13, 10/7/36, p. 4663. French Patent No. 793,602.) (2090 U.S.A.)

Lubricants suitable for high pressures and temperatures are made by suspending, in a mineral oil, non-corrosive particles acting as cushions. Such particles of larger than colloidal dimensions are:—

(1) Polymerised drying oils (including castor).
(2) Vulcanised organic substances (rubber).
(3) Insoluble hydrocarbon products (asphalt).
(4) Insoluble soaps (Al soap of oxidised aleurite oils).

Penetrating Oil Suitable for Loosening Rusted Connections. (B. H. Lincoln and A. Henriksen, Chem. Absts., Vol. 30, No. 13, 10/7/36, p. 4664. U.S.A. Patent No. 2,041,076.) (2091 U.S.A.)

Three per cent. of chlorinated stearic acid is added to a low boiling petroleum, butyl butyrate acting as solvent. Other examples are given.

Modern Tests on Fuels for High-Speed Diesel Engines. (A. Hagemann and T. Hammerich, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 775.) (2546 Great Britain.)

The " filtration index " at any desired temperature is obtained by comparing the time of flow of the oil through a 0.1 mm. mesh gauze in a special apparatus with the time of flow through the same apparatus without the gauze. The corrosion of Cu and Zn is examined by immersing strips of these metals in the oil at 50°. The tendency to form coke is shown by determining the hard asphalt and insoluble residue formed on heating the oil at 150° for 2 hr. in a stainless steel bomb with air at 20 atm. The conditions for determining knock-rating (cetene number) on the army Diesel test engine are briefly outlined. (See also Abstract No. 39/118.)

Distillation Curves of Lubricating Oils. (C. Walther, Chem. and Ind., Vol. 55, No. 35, 28/8/36, pp. 775-776.) (2547 Great Britain.)

It is considered that a pressure of 40 mm. Hg (as specified by the U.S. Bureau of Mines) is too high for distilling lubricating oil fractions. A laboratory apparatus is described which enables the distillation curve to be obtained under

a pressure of 10 mm. B.p. at one pressure are converted into b.p. at other pressures by means of the Beale-Docksey diagram.

Viscosities of Lubricating Oils at Low Temperatures. (Y. Tanaka and others, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 776.) (2548 Great Britain.)

The viscosity of numerous lubricating oils at temperatures down to $-35°$ agree fairly well with the empirical formula $\epsilon = e^c (T-b)^n$, where c, b and n are constants and ϵ is the ratio between the viscosity at T and at 303° absolute.

Relation Between the Properties of Lubricating Oil and its Chemical Structure. (H. I. Waterman and J. J. Leendertse, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 776.) (2549 Great Britain.)

The composition of a lubricating oil, *e.g.*, the proportion of aromatic and naphthene rings and paraffinic side chains, can be approximately deduced from determinations of mol. wt., n, d and NH_2 Ph point, making use of the molecular refraction. Correlation of the chemical nature of lubricating oils and their behaviour in practice may give useful results.

Laboratory Method for Determination of the Vaporisability of Lubricating Oils for Internal-Combustion Engines. (K. Noack, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 776.) (2550 Great Britain.)

Sixty-five g. of oil are electrically heated for 1 hr. at 250° under a pressure of 20 mm. H_2O in a weighed metal crucible and the loss in weight is determined. Duplication to ± 0.5 per cent. is claimed.

Production of Non-Knocking Motor Fuels. (J. Y. Johnson, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 778.) (2551 Great Britain.)

A mixture of alcohols, mainly butyl and higher alcohols, is obtained by heating CO and H_2 at $>$ 50 atm. in presence of a catalyst, *e.g.*, Zn O, Cr_2 O_3 Me OH is separated and the residual alcohols are dehydrated at 300° by catalysts, *e.g.*, Al_2 O_3 iso Olefines are thus obtained which are partly polymerised to di- and tri-merides by H_2 SO_4. The product is mixed with monomeric higher iso-alcohols (in some cases after hydrogenation of the latter) to give a motor fuel of high anti-knock value.

Fuels for Use in Internal-Combustion Engines and for Other Purposes. (R. G. Terakopoff, Chem. and Ind., Vol. 55, No. 35, 28/8/36, p. 778.) (2552 Great Britain.)

A mixture of paraldehyde (20-50 pts. by vol.) and a polycyclic hydrocarbon (50-80), *e.g.*, tetrahydronaphthalene, with or without a thin lubricating oil as upper cylinder lubricant, is added to liquid fuels for internal combustion engines in order to assist in initiating or promoting combustion of the fuel.

An aromatic amine, *e.g.*, NH_2PH, NHPhMe, or preferably aminocymene, may also be present. Normally 0.5 per cent. of the dope is added to gasoline and 1 per cent. to Diesel fuels.

Motor Fuel. (A. C. G. Egerton, Chem. Absts., Vol. 30, No. 15, 10/8/36, p. 5396.) (2559 U.S.A.)

Diesel or other engine fuel is doped with a peroxide in which one of the peroxide O atoms is attached to an alkyl or aliphatic acyl radical while the other is attached to H or to a sec. alkyl or aliphatic acyl radical. Thus 1-2 per cent. of diethyl peroxide is added to petroleum fuel oil, coal oil or creosote.

Relation Between the Constitution and Viscosity Characteristics of Hydrocarbons. (W. R. Wiggins, Chem. Absts., Vol. 30, No. 15, 10/8/36, p. 5400.) (2560 U.S.A.)

Since the change in viscosity with change in temperature depends upon the viscosity, the fractional viscosity temperature coefficient, $1/n \cdot \Delta n/t$, was proposed.

This was evaluated for 16 hydrocarbons of high mol. wt. by dividing the average change in viscosity per degree in intervals of 20° by the viscosity at the mid-point of the temperature range. The fractional temperature coefficient $=(n\ 20 - n\ 40)/20 \times n\ 30$. When these values were plotted against log. n, giving straight lines, the graph for aliphatic hydrocarbons was steepest, that for alkylated monocyclic hydrocarbons next, and that for polycyclic least. The expression

$$\Delta v/\Delta t \cdot 1/v \log. v$$

for viscosities in kinematic units was evaluated for three Pennsylvania and three Gulf Coast oils. The results were lower for the Pennsylvania oils throughout.

The expression differs from the viscosity index of Dean and Davis (C.A. 24, 716) in that it is not based on any arbitrarily chosen series of oils. The study included observations upon the influence upon the viscosity of branching chains, unsatn., cyclic structure, mol. wt. and mol. vol., polycyclic structures, etc.

Fatty Oils as Lubricants for Motors. (J. Hübscher, Chem. Absts., Vol. 30, No. 15, 10/8/36, p. 5401.) (2562 U.S.A.)

Olive oil, refined so as to remove free acids, proteins, and mucilage, can be used as a lubricant for automobile engines. Its stability and the relatively slight change in viscosity with varying temperature compares favourably with mineral oil.

Testing of Lubricants. (H. J. Gough and W. J. Clenshaw, Chem. Absts., Vol. 30, No. 15, 10/8/36, p. 5401.) (2563 U.S.A.)

Methods in use at the National Physical Laboratory are described.

A combination of bearing tests and engine tests has been evolved which is claimed to be of use in grading lubricants intended for motor car lubrication.

The Attack of Fuels on Various Materials. (K. R. Deitrich and W. Lohrengel, Chem. Absts., Vol. 30, No. 16, 20/8/36, p. 5757.) (2650 U.S.A.)

A series of 19 metals and alloys has been subjected to the action of an alc. mixture (95 parts abs. Et OH, 15 parts Me OH) and a benzine-alc. blend (10 per cent. of the alc. mixture) for ten weeks. Results of weekly detns. of metal weight changes are plotted showing the relative superiority of alloys over plain, galvanised and lead-covered iron.

Progress Report for 1935 on Lubricating Agents. (A. van der Wertl, Chem. Absts., Vol. 30, No. 16, 28/8/36, p. 5774.) (2651 U.S.A.)

U.S.A., British, German and French patents are listed with brief descriptions.

Relation Between the Standard Tests and the Quality of Lubricating Oils. (E. Thomas, Chem. Absts., Vol. 30, No. 6, 20/8/36, p. 5774.) (2652 U.S.A.)

A discussion of the practical significance of the viscosity index (Dean and Davis, C.A. 24, 716-717) and gravity index (McCluer and Fenske, C.A. 27, 834). The old idea that, of two oils having the same viscosity at the same temperature, the better is the one having the lower d, is confirmed by the calculation of the gravity index.

Oiliness Index as a Criterion of Lubricating Oil Quality. (F. W. Breth and L. Liberthson, Chem. Absts., Vol. 30, No. 16, 20/8/36, p. 5775.) (2654 U.S.A.)

The Sperry Adher-O-Scope uses a thin metal band to which an oil film is applied, revolving at high speed for a definite time in a conditional atmosphere, and constant temperature governed by the viscosity of the oil. The actual amount of oil adhering to the band is found to be an accurate and reproducible indication of the degree of oiliness.

The Laboratory Engine Testing of Motor Lubricants. (M. Fairlie, Gas and Oil Journal, Vol. 34, No. 44, 19/3/36, pp. 114, 117 and 119.) (2694 U.S.A.)

Experiments are carried out on a Waukesha type 2A four-cylinder unit. By means of a rapid ethylene glycol circulator, cylinder temperature is kept at 250°F. and crankcase at 220°F. or 320°F. The engine is run for 50 hours at 1,000 r.p.m., oil samples (100 cc.) being taken at intervals of 16, 32 and 50 hours.

The engine is started with one gallon of oil in the crankcase and replenishments are made after 16 and 32 hours. The drawn samples are investigated for :—

(1) Viscosity.
(2) Acidity
(3) Conradson carbon.
(4) Tar content.
(5) Induction period (this is number of hours required in Sinclair apparatus to reach 1 per cent. tar content).

During the test, the oil temperatures (pump discharge and sump) are noted, together with the flow of cooling medium required to maintain steady jacket temperature. A check is also kept on power and blow by temperature (crankcase breather).

With experience, the point at which ring sticking sets in can be approximately determined from a tendency for cylinder temperature to rise, blow by temperature to increase and power to fall.

Ring sticking tendency and tar content of final sample increase together, but not proportionally. This shows that quality as well as quantity of tar deposits count. For some of the oils tested, the carbon residue of the used oils gave a better indication of ring sticking tendency. It also appears that a high viscosity rise as such is not necessarily detrimental from a ring sticking point of view, unless the engine condition favours considerable blow by.

The test plant was also used to investigate corrosion of bearing metals. For this purpose two of the connecting rod big-end bearings were fitted with the test metals and the engine operated at an elevated crankcase temperature (320°F.) by jacketing with hot air.

The results are stated to be in agreement with full-scale experiments.

The Determination of the Specific Heat of Gases at High Temperatures by the Sound Velocity Method. II—Carbon Dioxide. (G. G. Sherratt and E. Griffiths, Proc. Roy. Soc., Series A, Vol. 156, No. 889, 1/9/36, pp. 504-517.) (2695 Great Britain.)

The principle of the method is the setting up of stationary sound waves at atmospheric pressure in a heated tube. The source of the wave system is a quartz crystal vibrating piezo-electrically. A movable reflector traverses the tube, points of resonance being determined by the sharply defined max. of the plate current of the oscillator operating the crystal. In this way the wave length and hence the velocity of sound can be determined, from which the specific heat values follow, using certain thermodynamic relationships. The experiments covered the range 0-1,000°C., and the values for the specific heat at constant

volume so obtained are in general above those given in the international critical tables.

Temp.	Present Investigation	International Critical Tables
0°	6.62 cal./gm. mole.	6.63 cal./gm. mole.
600°	10.81 ,,	9.15 ,,
1,000°	11.76 ,,	10.17 ,,

Purification of Exhaust Gases of Internal-Combustion Engines. (Chem. and Ind., Vol. 55, No. 37, 11/9/36, p. 820. British Patent No. 448,850.) (2714 Great Britain.)

The exhaust gases have different paths: (i) At low loads, (ii) at high loads. (i) May and (ii) must contain a purifier through which O_2 is also passed, *e.g.*, air is drawn sideways into a venturi throat.

Treatment of Exhaust Gases. (J. S. Kaufman, Chem. and Ind., Vol. 55, No. 37, 11/9/36, p. 820. U.S. Patent No. 2,021,690.) (2715 Great Britain.)

The gases from some of the engine cylinders are cooled down and the H_2O so obtained is brought in contact with Fe which is heated by the exhausts from the other cylinders. The resulting steam in the presence of iron oxide accelerates the oxidation of any CO present in the exhaust gas.

Lubrication Systems on Aero Engines. (German Patent No. 451,217. Engineer, Vol. 162, No. 4209, 11/9/36, p. 275.) (2733 Germany.)

A centrifuge is driven by an extension of the supercharger shaft. The used oil passes outward on one side of the centrifuge disc and inwards on the other, re-entering the hollow crankshaft extension.

The casing of the centrifuge can be opened periodically to remove sludge.

Generation and Absorption of Gas in Insulating Oils Under the Influence of an Electric Discharge. (G. W. Nederbragt, J. Inst. Elec. Eng., Vol. 79, No. 477, Sept., 1936, pp. 282-290.) (2834 Great Britain.)

It is known that insulating oils may give off gas, chiefly hydrogen, under the influence of an electric discharge. This generation of gas is particularly marked in the case of oils which have been exhaustively refined to make them more resistant to oxidation. In this paper an attempt is made to discover to what extent the generation of gas of refined oils can be suppressed by the addition of relatively small quantities of aromatics. Insulating oils always have a more or less extensive boiling range. If it is desired to have a slight tendency to generate gas, with a relatively small percentage of aromatics, it is important that the aromatics present should correspond to the lowest boiling constituents.

Measurements of Flame Velocity by a Modified Burner Method. (F. A. Smith and S. F. Pickering, Bur. Stan. J. Res., Vol. 17, No. 1, July, 1936, pp. 7-43.) (2862 U.S.A.)

This paper describes a study of the application of the burner method to the determination of the velocity of propagation of flame relative to mixtures with air of various combustible gases.

Observations have been made on the effect of varying the size of the burner port, of changing the velocity of flow of the mixture from the burner, of changing the composition of the mixture, and of different methods of measuring the flame and computing the result. All of these factors relate to problems of gas utilisation.

Pulverised Fuel Engines. Latest Development in Germany. (D. Brownlie, Chem. and Ind., Vol. 55, No. 39, 25/9/36, pp. 745-746.) (2875 Germany.)

At the Darstadt meeting of the V.D.I., reference was made to a 200 b.h.p. single cylinder engine (180 r.p.m.) operating on pulverised fuel. In order to prevent

undue mechanical wear, it is important that the ash content of the fuel be very low. Finely divided carbonaceous fuel like flour and starch will operate satisfactorily. In the case of bituminous coal, an ash free fuel can be extracted by a solvent treatment with tetraline under pressure (Pott-Broche Process). Details of this are not available but a large plant is stated to be in process of erection.

Diesel Fuel Specifications. (C. H. Barton, Chem. and Ind., Vol. 55, No. 39, 25/9/36, p. 867.) (2876 Great Britain.)

The significance of the tests normally employed in fuel specifications is discussed. The essential tests for a Diesel fuel of petroleum origin are viscosity at 37.8°, or 50°C, forming tendency, ignition quality (for high-speed engines), ash, and H_2O. Pour point or viscosity at low temperature may be required in special circumstances.

Correlation of Tests in Ignition Quality of Diesel Fuels Carried Out at Delft and Sunbury. (G. D. Boerlage and others, Chem. and Ind., Vol. 55, No. 39, 25/9/36, p. 867.) (2877 Great Britain.)

Normal Diesel fuels, including cracked fuels can be rated in terms of suitable mineral secondaries in almost any type of Diesel engine without serious risk that large differences will be found between one engine and another.

Modern Testing of Motor Fuels for the High-Speed Type of Diesel Engine. (A. Hagemann and T. Hammerich, Chem. and Ind., Vol. 55, No. 39, 25/9/36, p. 867.) (2878 Great Britain.)

In addition to the usual tests for Diesel oils, methods have been developed for filtering ability (difference in time of flow of 200ml. of oil through a special apparatus, with and without a gauze filter), corrosion (of Cu and Zn), ignitability (using a single-cylinder Deutz engine), and coking properties (determining the asphalt and coke on a sample after heating at 155° in a bomb under 200atm. air pressure). The effect of the fuel on the smoking point of the engine is important, but no satisfactory method for determining the latter point has been described. (See also Abstract No. 39/93).

Oil Oxidation. (R. W. Dornte and C. V. Ferguson, Chem. and Ind., Vol. 55, No. 39, 25/9/36, p. 867.) (2879 Great Britain.)

The oxidation of lubricating oils (unaffected by the reaction products) is approximately proportional to the partial pressure O_2, H_2O and CO_2 but no peroxides are formed and inhibitors are practically without effect. Cu increases considerably the rate of oxidation but Fe, Sn and Pb have only a slight accelerating influence.

Precision Attainable in Knock Rating of Fuels for Internal-Combustion Engines. (J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, pp. 365-366.) (2887 U.S.A.)

From an analysis of 2,180 tests carried out on 99 fuels, the Bureau of Standards concludes that the probable error for the average of these fuels is less than ½ octane No. The precision of rating is nearly the same for straight run petrols, blends of straight run and cracked and for leaded fuel of any base.

The error is greater for non-leaded cracked fuels and benzol blends. The octane number depends in some cases on atmospheric humidity. Accuracy is thus improved by air conditioning as well as by limiting the period between overhauls to 50 hours.

In all cases it is important that the knock intensity be kept constant throughout the tests.

Bromine Plant of Ethyl-Dow Chemical Co. (J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, p. 388.) (2889 U.S.A.)

During the 2½ years of operation, the plant has extracted 10.000 tons of Bromine from sea water. (Weight of water treated app. 130×10^6 tons).

Most of this Bromine has been used in the preparation of Ethyl Fluid.

A Differential Thermoscope. (G. Rempp, Comp. Rend., Vol. 202, No. 23, 8/6/36, pp. 1937-1939.) (1805 France.)

The author proposes to adapt the cooling meter of Thilenius (Met. Zeit., Vol. 48, 1931, p. 254.) so as to record small wind speeds. For this purpose two identical recipients made of polished copper and connected by means of a manometer, are exposed to the wind. An electric heater is incorporated in the wall of one of the vessels and the heating circuit is broken when the temperature difference between the two vessels (as recorded by the manometer) reaches a definite value. The current is similarly re-established when the temperature difference has fallen a prescribed amount.

The quantity of electricity required is a measure of the cooling effect. This in its turn can be linked up with the strength of the wind, by means of a suitable calibration.

Electric Pressure Recording Device. (A. Hasse, Z.V.D.I., Vol. 80, No. 19, 9/5/36, pp. 563-564.) (2043 Germany.)

An electric condenser is built up of three plates, the dielectric (air) being pressure sealed. Variation of external air pressure causes small movements of the outer plates (1/100 to 1/1000 mm.) and thus varies the electric capacity. A single valve amplifying circuit is described which gives variation of capacity directly on a sensitive current indicator. The dimensions of the condensor are kept small (2-3 mm. diameter) and rapidly varying pressures (1000/sec.) can be recorded on an oscillograph, the available current being of the order of 10^{-3} A for 1/100 mm. water gauge. The instrument is principally intended for accurate altitude measurements, the sensitivity being of the order of 1 m. for altitudes between 0 and 250 m. By altering the electric constants of the circuit, greater altitudes can be recorded.

Time Lag in a Control System. (A. Callender and others, Phil. Trans. Roy. Soc., Vol. 235, No. 756, 21/7/36.) (2391 Great Britain.)

The " law of control," or relation between the behaviour of the quantity to be controlled and the effect (after the expiration of the time-lag) of the consequent control operation on it, is taken to be linear in the quantity controlled, its time derivative and time integral. For stable control the damping constants of all the normal modes must be positive and this, coupled with the requirement of quick return of the quantity controlled to its normal value after a disturbance, limits the practically useful range of values of the parameters in the law of control. A practical method, feasible on the industrial scale, for obtaining automatic control approximately in accordance with a law of control of the form here studied, is outlined, and two analogous methods are indicated.

Joliet Reference Gas Meter. (H. S. Bean and others, Bur. Stan. J. Res., Vol. 17, No. 2, August, 1936, pp. 207-246.) (2836 U.S.A.)

The meter is of the proportional type in which the main gas stream is divided into a large and a small stream, the latter being measured directly by means of a piston meter.

The actual ratio of the mass rates of the two gas streams is determined by a thermal method. Two heat exchangers, one in each gas stream, receive heat through the medium of hot water from a common source. The rates of flow of the

hot water to the two heat exchangers are adjusted until the temperatures of the outlet water streams are the same.

The rates of flow of the gas in the two streams are then adjusted to bring together their temperatures on the outlet side of the heat exchangers. The ratio of the mass rates of flow of the gas streams is now equal to the ratio of the mass rates of flow of the water streams.

The latter can be readily measured by weighing and since the rate of flow of the small gas stream is known from the piston meter the main flow can be calculated.

The New R.C.A. Radio Compass. (Aero Digest., Vol. 29, No. 2, Aug., 1936, pp. 38-40.) (2421 U.S.A.)

The new type A.V.R. 8 weighs 20 kg. and is operated by a 12 v. battery.

The circular antenna is 20 cm. diameter and housed in a streamline case.

The radio compass gives simultaneous optical and acoustic indications.

The 10 valve superhet receiver ensures telephone communication (weather news) simultaneously with direction finding.

An installation diagram is given.

The Petoscope: A New Principle in Photo-Electric Applications. (A. S. 'Fitzgerald, J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, pp. 289-325.) (2884 U.S.A.)

The object is viewed by means of two photocells, the light having to pass through two fine meshed grids one being placed in front of each cell. If the dimensions of the object are comparable with the spacing in each grid, a displacement of the object relating to the background will cause an alternating stimulation of the cells, the frequency of the alteration depending on the velocity of movement, the distance of the object and the dimension of the grid divisions. A change in illumination will, however, cause no pulsation.

By using suitable amplification, extreme sensitivity and stability can be combined. The apparatus will detect the passage of aircraft at altitude up to 2,000 feet from the ground. Other possible applications are described.

The Consumption of Energy and the Production of Heat in a Vibrating Steel Bar. (A. Ono, Z.A.M.M., Vol. 16, No. 1, Feb., 1936, pp. 23-32.) (1731 Germany.)

The author has measured the mechanical energy employed and the heat produced, in the flexural and torsional vibrations of a steel bar. After describing the apparatus for measuring the vibrations and the method for calculating the conduction of heat, he indicates and analyses the results of his experiments. He shows in particular, that the stationary state of motion, where the energy employed equals the heat produced, is reached only after a considerable number of vibrations.

On the Buckling of a Curved Rod. (A. Lockschin, Z.A.M.M., Vol. 16, No. 1, Feb., 1936, pp. 49-55.) (1734 Germany.)

Setting out from the general differential equations and boundary conditions of the problem, the author integrates them in some special cases by the method of Adams-Störmer and finds the buckling load by calculating the first characteristic value.

Concerning a New Method of Obtaining Highly Polished Metallic Surfaces. (P. Jacquet, Comp. Rend., Vol. 201, No. 27, 30/12/35, pp. 1473-1475.) (1938 France.)

So far the method only applies to copper and some of its alloys. The article requiring polishing is made the anode, the cathode being a plate of copper of slightly larger dimensions. The electrolyte consists of an aqueous solution or

ortho or pyrophosphoric acid. Over a certain limited range of applied voltage and current density, the surface of the anode facing the cathode becomes shiny, the surface being superior to that obtainable by ordinary polishing.

Treated Fabrics for Oil Pump Diaphragms. (U.S.A. Patent No. 2,041,836. Chem. Absts., Vol. 30, No. 14, 20/7/36, p. 5026.) (2308 U.S.A.)

A fabric such as a mercerised cotton cloth is impregnated with a drying oil such as linseed oil containing 0.25-2.0 per cent. of a polyaryl guanidine, phenyl-α-naphthylamine, *p*-hydroxydiphenyl, catechol, α-naphthol or creosol, and then dried.

Stiffness in Stressed Skins. (E. H. Atkin, Airc. Eng., Vol. 8, No. 90, August, 1936, pp. 213-217.) (2337 Great Britain.)

Many types of stiffened skin constructions require stringers at such a pitch that the structure is not acting as a tension diagonal system. The presence of residual compression reduces the loading on the booms or other boundary members. This limits the application of the Wagner tension diagonal theory.

The complete rational solution of the problem is difficult and the author offers his investigation as an intermediate step which enables quantitative predictions to be made in certain cases.

Fabric in Shear. (Airc. Eng., Vol. 8, No. 90, August, 1936, pp. 227-228.) (2342 Great Britain.)

This is an instructive experiment in connection with the theory of thin sheets in spar webs.

According to the Wagner theory, the shear is carried by a diagonal tension stress combined with a compressive stress in vertical stiffeners.

In a normal spar web, the shear load is carried by a shear stress in the web which may be stiffened to prevent buckling.

A test piece was made up using fabric as a material for the web of the spar which has no resistance to buckling but a good strength in tension.

Experiments showed that the structure failed at an average stress of 48lb. per inch width of fabric.

The tensile strength of the aircraft fabric used should have been 80lb. per inch width.

The difference may be partly accounted for by the lie of the threads not coinciding with the direction of the tension diagonals.

The change in appearance with increase in load of the web from an even wrinkling over its surface to a generally flat surface with deep wrinkles at the end of the stiffeners may indicate the necessity of careful design in a real spar at this point.

On an Experimental Method for the Solution of Plane Stress Problems. (L. Chitty and A. J. S. Pippard, Proc. Roy. Soc., Series A, Vol. 156, No. 889, 1/9/36, pp. 518-537.) (2696 Great Britain.)

The model is made of thin rubber sheet, floating on mercury. It is held and loaded according to the nature of the problems under investigation, any tendency to buckle being prevented by placing small weights on the surface.

The displacements under load of selected points on the surface are measured by means of a micrometer microscope. From the slope of these curves, the stresses can be calculated, using the elastic properties of the rubber as previously determined. The method was applied to the study of a disc supported on a central hub and loaded radially over a small arc. This problem was studied

theoretically by the authors (Phil. Mag., Vol. 21, No. 138, Jan., 1936, p. 106) and the experimental agreement is good.

It is hoped that further development in technique will make the method useful for obtaining stress distribution in cases not amenable to mathematical analysis.

Improvements Relating to Aircraft Wing Covering. (French Patent No. 765,347. L'Aéronautique, Vol. 18, No. 206, July, 1936, p. 96.) (2817 France.)

A shell construction for wings, is proposed using neither ribs nor spars. The material consists of compressed cork which is glued between two layers of metal or plywood, the outer surface being sprayed with a layer of aluminium. The shear resistance of the cork exceeds 1 kg./cm.^{2}. The principal advantage claimed is high internal damping against vibrations.

Corrosion Behaviour of Painted Iron and Inhibitive Action of Paints. (R. M. Burns and H. E. Haring, Bell Tele. Pubs. No. 928, 1936.) (2833 U.S.A.)

The corrosion behaviour of bare iron can be determined by measurements of its potential and change in potential time. With the aid of a vacuum tube electrometer this method of study has been extended to the determination of the corrosion behaviour of painted iron and the mechanism of the inhibitive action of paints. Red oxide ($Fe_2 O_3$) and red lead ($Pb_3 O_4$) have been studied both as pigments and primers. The validity of the method has been demonstrated by the fact that it confirms conclusions which have been obtained only after many years of practical experience, i.e., that the corrosion inhibitive action of red oxide primer is purely physical, while that of red lead is essentially chemical. Both types of protective paint may maintain iron in the passive condition ; the former by keeping the iron dry, the latter by chemically passivating it in the presence of moisture.

Determination of the Brinell Number of Metals. (S. N. Petrenko and others, Bur. Stan. J. Res., Vol. 17, No. 1, July, 1936, pp. 59-95.) (2863 U.S.A.)

The procedure used in making Brinell tests must be closely controlled in order that two observers testing a given metal at different locations should obtain Brinell numbers that are in close accord. Small variations in testing procedure will be inevitable so that it becomes important to know the effect of these variations on the magnitude of the Brinell number obtained. The present paper considers the effect on the Brinell number of such variation with the help of data available in the literature supplemented by new tests wherever the existing data seemed deficient.

Fatigue Impact Testing Machine—Type Maybach—for Light Alloys. (R. Lante, Z. Metallk., Vol. 28, No. 8, August, 1936, pp. 233-236.) (2891 Germany.)

Previous testing machines measured the impact by the work done in Kg. cm. Such machines are sensitive to method of support, shape and rigidity of specimen, moreover the testing time is rather long. In the Maybach apparatus described, a cylindrical test piece 9 mm. in diameter and 150 mm. long is supported at its ends and subjected to simultaneous impact of 2 cams operating at 70 mm. from each end. The advantage of this machine is that the impact loading can be measured in kg./mm.^{2} 60 to 80 blows per second can be given and time of experiment is restricted.

The Temperature of Atmospheric Ozone. (M. J. Devaux, Comp. Rend., Vol. 201, No. 27, 30/12/35, pp. 1500-1501.) (1934 France.)

The temperature was estimated from a study of the infra-red spectra of the sky obtained at the observatory of Pic du Midi (altitude 2,860 m.). From the intensity of the absorption band at 10μ, it is estimated that the ozone belt is at an average temperature considerably below O °C and does not undergo any marked diurnal or seasonal variations.

The Physiology of the Aviator. (G. Schubert, Rev. de l'Arm. de l'Air, No. 85, Aug., 1936, pp. 953-958.) (2883 Germany.)

The French reviewer of this medical book hails it as the standard reference work for every doctor. Of special interest are the chapters dealing with acrobatic and high altitude flying. The maximum acceleration which can be supported by the trained individual is 5 g. (head to feet) but only 2½ g. (feet to head). The amount of blood in circulation increases with height but is unlikely to produce heart stressing.

The importance of the labyrinth in giving the pilot "air sense" is discussed. It appears that modern medical research will influence present day regulations for the acceptance and supervision of pilots.

Carbon Monoxide Indicator for Aircraft. (J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, pp. 366-367.) (2888 U.S.A.)

The maximum amount of CO in air to which a person may be exposed without harm for one hour is .04 per cent at ground level and less at altitude.

As risk of CO pollution exists in aircraft cockpits (either from leaks in exhaust pipe or inflow of exhaust gases by air currents), the Bureau of Standards have modified commercial CO indicators to make them available for aircraft. An alarm has been developed which sounds if the CO concentration exceeds .02 per cent. A full description is given in N.A.C.A. Tech. Note No. 573.

High Speed Photography. (H. E. Edgerton and others, Sci. Absts. (Section B), Vol. 39, No. 462, 29/6/36, p. 383. Phot. J., 76, pp. 198-204, April, 1936.) (1901 Great Britain.)

The authors briefly describe a method of high-speed photography developed for the study of oscillations of synchronous motors following changes in load and during the transient period of the motor as it endeavours to pull into synchronism. The control of the illumination, which is obtained from discharge tubes, is by means of electronic amplifiers, these consisting of a condenser, induction coil and grid-controlled mercury-arc rectifier. The grid of the rectifier is actuated by a commutator on the camera, thereby spacing the pictures correctly. A speed of 1,200 pictures per sec. is obtained with full-frame 35 mm. pictures, capable of increase up to 6,000 per sec. by reducing the frame size.

The Thermal Conduction of Glycerine Water Mixtures. (S. Erk and A. Keller, Phys. Zeit., Vol. 37, No. 10, 15/5/36, pp. 353-358.) (1723 Germany.)

Model experiments on heat transfer (law of similarity) require the knowledge of the thermal conductivity of the fluid. This has generally restricted the experimenter to the use of water, since only for this fluid are the physical constants known with sufficient accuracy. Unfortunately the viscosity of water is considerably less than that of most fluids of interest to the heat engineer. This renders convection phenomena difficult to reproduce. For this reason the authors have determined the thermal conductivity of glycerine-water mixtures at temperatures varying from 7 to 70°C. The glycerine content varied from 0 to 100 per cent. and the estimated accuracy of the conductivity is ± 2 per cent.

(See also O. K. Bates, Ind. and Eng. Chem., Vol. 28, No. 4, April, 1936, pp. 493-498).

Short Wave Phase Measurements for Blind Landing. (K. Bärner, Sci. Absts. (Section B), Vol. 39, No. 461, 25/5/36, p. 329; from Hochfrequenztechn u. Elektroakustik, 47, Feb., 1936, pp. 45-55.) (1686 Germany.)

The author investigates the possibility of using phase measurements at very high frequencies, of the order of 10—20 m. wave-length, as a means of ascertain-

ing small heights above the ground for the blind landing of aircraft. An open oscillator was used which could be elevated above the ground from a tower. The phase-measuring circuit consists of 2 valves in push-pull. A comprehensive series of curves relate the phase of the current with height and wave-lengths, for different types of open oscillatory circuits. The effect of reflections from the earth, giving interference effects, is evident, and is considered by the author.

Micro-Ray Communication. (W. L. McPherson and E. H. Ullrich, J. Inst. Elec. Eng., Vol. 78, No. 474, June, 1936, pp. 629-657. Discussion, pp. 658-667—52 references.) (1741 Great Britain.)

This excellent paper starts with a short historical review of the evolution of wireless communication. The method of generation and modulation of micro-rays around 17 cm. with a tube having two grid lead-outs is discussed, and it is argued that the grid itself becomes a transmission line of negative leakance. Some experiments with ebonite lenses and zone plates are described. Paraboloidal mirrors, echelon gratings, and hemispherical mirrors, are discussed.

The micro-ray equipments used on the commercial Lympne-St. Inglevert and the experimental Escalles-St. Margaret's links are described. Propagation measurements on these last two links are detailed and it is shown that, although there is an optical path in each case, severe fading, which is different on different wavelengths, sometimes takes place. This fading is attributed to an interference pattern which varies with atmospheric and tidal changes.

The directivity and gain by using paraboloidal mirrors and echelon gratings, as determined by experiment, are given.

In conclusion, future possible uses of micro-rays are sketched.

The extremely small size of aerial required would render micro-waves especially suited for aircraft communication. Difficulties arise, however, from reflection of the waves by the metal (or metallised) parts of the structure.

High Speed Electric Motors. (R. C. Colwell and N. I. Hall, J. Frank. Inst., Vol. 221, No. 6, June, 1936, pp. 797-805.) (1783 U.S.A.)

In this paper, two new types of electric motors are discussed which are capable of rotating 100,000 r.p.m. A synchronous motor is described but the emphasis is placed upon the new design of the induction motor. This motor is mounted upon a single bearing and for high speeds must be run in a vacuum.

The high frequency current (3,000 r.p.s.) is produced from a two phase Alexanderson alternator, which is described. The circuit of this alternator must be tuned to resonance. The velocity of the rotating motor is measured with a new type of Stroboscope which has a wide range of values and is easily calibrated.

Aluminium alloys for the discs and commercial bearings have been tested and found suitable for speeds up to 75,000 r.p.m.

A Method of Improving the Efficiency of Electrostatic Motors. (P. Jolivet, Comp. Rend., Vol. 202, No. 25, 22/6/36, pp. 2051-2052.) (1940 France.)

Reference is made to the electro-static generator described previously (see abstract, Abstracts and Notices No. 38, item 151).

By enclosing the motor in an airtight chamber both the supply voltage and the power output increase with increased air pressure.

At a constant speed of rotation (300 r.p.m.) the power output of this particular motor (10 cm. plate weighing 20 gm.) rose from 0.37 watts (atmospheric pressure) to 2.84 watts (4.5 atmospheric absolute). At this output, the efficiency exceeded 40 per cent.

Rain Static. (H. K. Morgan, Proc. Inst. Rad. Eng., Vol. 24, No. 7, July, 1936, pp. 959-963.) (2039 U.S.A.)

The problem of rain static, particularly as it affects aircraft is treated. Rain static is due to particles of rain, snow, or dust striking aircraft antennas. It has been found that the disturbance is electrostatic in origin and that an electrostatically shielded loop antenna reduces it materially.

High Voltage Mercury-Pool Tube Rectifiers. (C. B. Foos and W. Lattemann, Proc. Inst. Rad. Eng., Vol. 24, No. 7, July, 1936, pp. 977-984.) (2040 U.S.A.)

Mercury-pool tubes of the ignition type offer attractive features for power rectifier service. This paper discusses the application of this type to controlled high voltage, high power rectifiers to radio transmission, and some problems peculiar to their use as such. An experimental rectifier of this type, which has been in operation, is described.

Ionosphere Studies during Partial Solar Eclipse of February 3, 1935. (S. S. Kirby and others, Proc. Inst. Rad. Eng., Vol. 24, No. 7, July, 1936, pp. 1027-1040.) (2041 U.S.A.)

Virtual height and critical frequency measurements of the several regions of the ionosphere were made during the day of the solar eclipse of February 3, 1935, and during several days before and after the eclipse day. The eclipse was found to produce a decrease of the critical frequency of each region. The decrease of critical frequency was approximately in time phase with the eclipse, thus indicating an ionising agency (probably ultra-violet light), originating in the sun and propagated at approximately the velocity of light.

A New Electron Tube having Negative Resistance. (J. Groskowski, Proc. Inst. Rad. Eng., Vol. 24, No. 7, July, 1936, pp. 1041-1052.) (2042 Poland.)

The dynatronic and magnedynatronic systems commonly used to obtain a negative resistance by means of triodes or tetrodes are characterised by the fact that the potential of the active electrode (the anode) is not the highest potential in the system; an electrode (the grid or the screen grid) at a higher potential is necessary in order to take off the secondary emission current from the anode in such a way that a falling characteristic is produced in the anode circuit.

The present paper deals with a three-electrode tube of such design that the negative resistance is obtained in the circuit of the electrode possessing the highest potential in the system.

Preventing Collisions in the Air. An American Radiaura. (Aeroplane, Vol. 51, No. 1315, 5/8/36, p. 177, and 1316, 12/8/36, pp. 212-213.) (2505/2323 Great Britain.)

Both instruments utilise the cathode ray tube.

(1) *English Construction.*

The proximity of a sending station is recorded by the lengthening of a luminous line on the screen of the cathode ray tube. Two fixed ring antennæ at right angles are employed.

(2) *American Construction (U.S. Coast Service).*

A fixed and a movable antenna are joined via amplifiers to the deflecting plates of the cathode tube.

When approaching transmitting station a vertical line is seen on the screen. Deviation, of course, is shown by inclination of line to right or left.

Closer proximity to the home station is indicated by the appearance of an ellipse or circle on the screen. Vertically above the transmitting station a single dot is recorded.

With a 50 kw. transmitter, the range is 200 to 300 km.

Technical Details of the Television Sending Station of the Eiffel Tower (Paris). (J. Le Duc and R. Barthélemy, Revue Générale de l'Electricité, Vol. 39, No. 18, 2/5/36, pp. 651-661.) (2589 France.)

Details are given of the studio, the machinery installation and the antenna. The studio is situated at some distance from the Eiffel Tower and this necessitated a cable 2,000 m. leading to the machinery hall. A feeder cable, 320 m. long, leads from this to the antenna proper situated near the top of the tower. The transmission is on a wave length of 8 m., the radiated energy being of the order of 1 kw. (supplied energy = 2.5 kw.). The image analysis is carried out with 180 lines (25 images per second).

Unlike the American system (Zworykin and Fainsworth) which is purely electronic, the system adopted on the Eiffel Tower is mechanical and largely based on experience gained with the 60-line transmission (180 m. wave length) already in regular use by the French Post Office.

The difficulties due to the stepping up in number of lines have been met by

(*a*) An improved spiral scanning disc with special obturator.
(*b*) Special photo-electric cells (gas filled).

The synchronisation system has already been described in a previous number (Revue Générale de l'Electricité, Vol. 38, 31/9/35, pp. 405-410). At the end of each analysing line a short signal is emitted in the inverse direction to the brightness impulses. This signal only lasts 1/100 of the time taken for the transmission of one picture line. Television pictures by this process are on view at a number of public places in Paris so that the public are kept in touch with developments. Attempts are being made to improve sensitivity of camera and reduce illumination of studio. At the present time the heat generated is such that very active ventilation is required in the studio and this in its turn introduces difficulties due to noise. It is hoped that a more efficient system (10 kw. radiated in antenna) will be available for the International Exhibition in 1937.

Electrical Measurements at Wave Lengths Less than Two Metres. (L. S. Nergaard, Proc. Inst. Rad. Eng., Vol. 24, No. 9, Sept., 1936, pp. 1207-1229.) (2828 U.S.A.)

In this paper the measurement of power and voltage at ultra-short waves is considered. A signal generator delivering adequate power output with satisfactory stability over the wave length from twenty to 200 centimetres is described. The requirements of thermocouples satisfactory for the measurement of power are considered and a set of thermocouples covering the power range from 0.1 milliwatt to fifty watts is described. A study of vacuum tube voltmeters has shown that diode voltmeters have very small loading (of the order of 15° ohms) on the circuits to which they are connected, whereas conventional triode voltmeters using RCA–955[15] have an input impedance of about 10^4 ohms at a wave length of one metre. The errors of diode voltmeters at ultra-short wave lengths have been studied.

On the Anomalous Properties of Dielectrics. (J. Neufeld, J. Frank. Inst., Vol. 222, No. 3, Sept., 1936, pp. 327-336.) (2886 U.S.A.)

The causes of energy losses in dielectrics subjected to alternating stresses are not completely understood. One of the most satisfactory methods of treating

these problems, due to von Schweidler, attributes the dielectric loss entirely to dielectric absorption. Some agreement between the methods of von Schweidler and experimental data has been found by F. Tank, J. B. Whitehead and R. R. Benedict. However, there does not exist a satisfactory test of the accuracy of the analysis of von Schweidler. The present paper gives:—

(1) A method of separating the losses due to absorption in dielectrics.

(2) A method for determining analytically the absorption curve of a dielectric in which hysteresis is absent.

(3) A graphical method of checking the accuracy of von Schweidler's analysis.

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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AEROPLANES—CONSTRUCTION.

450,083. *Improvements in or connected with Means for Attaching Fabric Coverings to the Metal Structure of Aircraft Frames.* Short Bros., Ltd., and Clark, A. W. C., both of Seaplane Works, Rochester, Kent. Dated March 14th, 1936. No. 7,741.

The object of this insertion is to attach fabric to the structure so that neither the warp or weft is severed but also to enable the surface at the attachment to be given a smooth finish. The attachment means consists in forming the structure with a series of grooves in line with each other leaving posts between the grooves flush, thus forming flat bridge pieces and providing a fabric retaining device adapted to pass under the bridge pieces and to lie within the grooves. The grooves may be closed at the bottom or they may be openings into which parts of the fabric may be depressed. The fabric is held down by a tool into these grooves while a pointed wire skewer is traversed through the grooves when the tool is removed. Afterwards a strip of adhesive can be applied over the exposed skewer.

450,596. *Improvements relating to the Securing of Short Members to a Wooden Batten by Means of Staples.* Calver, B. G., 52, Linver Road, London, S.W.6. Dated July 15th, 1935. No. 20,214.

In order to secure two sheet members, such as three-ply wood, together at an angle to each other, it is proposed to use a batten in the corner and to fix the sheets to this with machine drawn staples, which may or may not be clenched. Glue may also be used. Various joints made on this principle are described, some with two battens and others in which the sheets are secured by staples in grooves in the batten.

454,198. *Improvements in and relating to Tail Skids and Tail Wheels for Aircraft.* Elektronmetall G.m.b.H., 26, Stuttgart Bad Cannstatl, Germany. Convention date (Germany), Feb. 19th, 1935.

This is a skid or tail wheel for aircraft with a shock absorber built into the back part of the fuselage so as to rise rearwardly and a tail skid or tail wheel element, the vertical swinging axis of which is nearly vertical or inclined at a small angle towards the front and in which the support bearing is connected with the lower end of the shock absorber so as to move in a straight line in the direction of the axis of the shock absorber.

AEROPLANES—GENERAL.

451,879. *Improvements in or relating to Aircraft and other Vehicles.* Ramsbottom, J. E., Lockspeiser, B., and Stewart, C. J., all of the Royal Aircraft Establishment, South Farnborough, Hants. Dated May 8th, 1935.

This specification refers to the prevention of ice formation on aeroplane wings, and consists of a permeable nose covering to the wing through which a suitable liquid, such as Ethylene Glycol can percolate. The liquid is led to the nose by tubes, holes in which carry absorbent threads which pass through the apertures and act as wicks, thus distributing the liquid from the interior of the tube to the absorbent covering. Reference is made to Specification No. 10549 and Serial No. 56099.

453,030. *Improvements in or relating to Aerofoils.* Muschler, F., Benville Township, Morris County, New Jersey, U.S.A. Dated Oct. 11th, 1935. No. 28,160.

This specification describes what is claimed to be an improved aerofoil of the type in which the leading edge is substantially semi-circular in plan. The trailing edges converge in one or more points and in which a pusher propeller is mounted at each of sail points. The machine has a plan form of low aspect ratio of what is described as raindrop shape, with its greatest dimension parallel to the line of flight.

453,825. *Method of and Means for Warming the Wings and Other Parts of Aeroplanes.* Schmid, F., Eiken, Aagan, Switzerland. Dated June 28th, 1935. No. 1,257.

It is stated that it is inadvisable to introduce exhaust gases into a wing for the purpose of warming it owing to the effect of these gases on the material of which a wing is constructed. It is proposed, therefore, that air warmed by passing through a chamber, through which the exhaust pipe also passes, shall be used for this purpose. Timing arrangements may be used for increasing the heat transfer, and the hot air is conducted through the wing by a pipe suitably pierced with holes for its escape. The end of the pipe is taken to the wing tips and the orifice is turned rearward, so as to increase the flow through the pipe. Other portions of aircraft may be warmed in the same way.

455,023. *Improved Aeroplane having a Variable Lifting Surface.* Gerin, J., 24, Rue de la Tourelle, Boulogne-sur-Seine (Seine), France. Convention date (France), April 7th, 1934.

This specification refers to aeroplanes in which the wings are increased in depth for low speed landings by means of flexible movable surfaces which may be wound on drums. It is proposed that the operating drums be driven from a reversible motor by means of free wheels, or the like, so arranged that the free wheel driving the operating drum for the flexible surface is actuated in its free direction and with a certain lead when the flexible surface is spread out, the free wheel for the cable drum being then actuated in the driving direction.

454,820. *Improvements in or connected with Apparatus for Discharging Fuel or other Liquid from Aircraft.* Short Bros. (Rochester and Bedford), Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated Dec. 19th, 1935. No. 35,206.

This is a jettison valve intended primarily for the fuel tanks of aircraft. It consists of a mushroom valve in the tank which is assisted to keep on its seat by the tank fuel pressure. The pipe leaving the tank, into which pipe the valve discharges when open, is bent near the tank so as to permit the valve stem to emerge from the tube. The valve is opened by a hand wheel and screw gear. A special packing seals the valve stem hole when the valve is open.

454,388. *Improvements relating to Aeroplanes.* Griffen, G., 56, Ludgate Hill, London, E.C.4. Dated April 1st, 1935. No. 10,094.

This specification describes an aeroplane of the Burnelli type in which the wing has a central section of the convex aerofoil contour of sufficient depth to accommodate passengers and outer wing sections tapering in plan and depth, but having substantially the same chord at the root and the same upper camber at the root as, but considerably less depth than, the centre section whereby a wing is obtained having a continuous upper surface.

454,556. *Improvements relating to Aircraft.* MacDonald, R. (Miss), 81, South Audley Street, Mayfair, London. Dated March 27th, 1935. No. 9,544.

In the case of aircraft wings it is proposed to add an auxiliary wing of triangular form which is accommodated beneath, inside or on top of the main wing, this auxiliary being attached to the fixed wing by a ball joint near the tip. It can be drawn out rearwardly by mechanism in the fuselage, can have its incidence adjusted, and a slot may be formed between the main wing and the auxiliary.

454,096. *Improvements in or relating to Aeroplanes.* Philippichs, S., 200, Royal Exchange, Manchester, Lancaster. Dated March 23rd, 1935. No. 9,081.

The proposed aeroplane is provided with supporting surfaces and air current producing means so arranged that the currents flow beneath and parallel to the plane of the surfaces to produce lift without the employment of translation. The air currents may be produced by fans, or mechanical or electric draught-producing means, etc.

454,193. *Improvements in Aircraft.* Gerin, J., 24, Rue de la Tourelle, Boulogne-sur-Seine (Seine), France. Convention date (France), Nov. 17th, 1934.

The aeroplane described has variable wings of flexible construction which can be operated by drums on which the flexible surfaces can be wound. It also has a fuselage, the transverse ribs of which have a horizontal axis the length of which continually increases from the front to the trailing edge of the empennage, while the vertical axis varies for giving an aerodynamic profile.

AEROPLANES—UNDERCARRIAGES.

452,324. *A System of Retractable Landing Gear for Aeroplanes.* Société d'Inventions Aeronautiques et Mecaniques S.I.A.M., 1, Route des Alpes, Fribourg, Switzerland. Convention date (France), Jan. 12th, 1935.

This is a retractable chassis of the type which folds backwards into the wing. In the extended position there is a shock-absorbing strut on each side of the wheel and a diagonal member inclined upwards and forwards containing the retracting jack, and a further directing bar hinged to the wing and to the shock-

absorbers. On operation, the shock-absorbing struts break above the shock-absorbers and the wheel retracts backwards as stated.

453,797. *Improvements in Brake-Operated Mechanism for Aircraft.* Bendix, Ltd., King's Road, Tyseley, Birmingham, and Hall, P. E., of the same address. Dated July 10th, 1935. No. 19,681.

A cable from a hand control is coupled to one end of a lever pivoted at its other end to a cage secured to the machine. At an intermediate position on the lever are two coaxial pulleys round which cables from the foot brakes are led in opposite directions. Their ends are secured to points on opposite sides of a rocking bar pivoted on the cage and coupled to the rudder bar so that the two move together. To apply the brakes equally the cable from the hand control is tensioned, thereby moving the lever carrying the pulleys and applying both brakes equally. If the rudder bar is operated the rocking bar moves with it and the anchorage for one brake cable is moved towards the pulleys while the other is moved away, so that the force applied to one brake is increased and that applied to the other is diminished. When the hand control is off there is sufficient slack in the cables to permit of a normal movement of the rudder bar.

450,929. *Improvements in or relating to Retractable Undercarriages for Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Ordidge, F. H., 24, Carlton Avenue, Cheadle Hulme, Cheshire. Dated July 9th, 1935. No. 10,413.

In this folding undercarriage the wheel is arranged to fold backwards into the wing. The wheel is carried in a fork attached to a single tube vertical member containing the shock absorbing gear. This tube carries a member in which is a diagonal slot. Working on a pin sliding in this slot is a jack pivoted on the shock-absorbing tube, and a further rigid radius member hinged rearwardly in the plane. On admitting fluid below the jack piston the chassis is retracted into the wing.

450,771. *Novel or Improved Method of and Means for Controlling the Movement of Aeroplanes when Landing or Travelling on Land.* Colbourne, J. H., "Wear Giffard," Cliff Hill, Warwick. Dated Jan. 29th, 1935. No. 2,844.

This specification describes a differential braking arrangement for aircraft. In this case, instead of interposing the differential leverage device between the brakes proper and the brake pressure originating device, it is situated at one end of the system to function as a reaction anchorage. The arrangement has a lever with a variable fulcrum point, which fulcrum point slides in a curved slot. Other arrangements which are similar mechanically are also proposed.

450,922. *Improvements relating to Landing and Taking-off Gear for Aircraft.* Beadon, R. R. C., The Glen, Valley des Vaux, St. Helier, Jersey, Channel Islands. Dated Feb. 10th, 1936. No. 4,037.

The chassis proposed is said to comprise the known principle of assisting aircraft into the air by a vaulting action similar to that employed by birds. It is therefore proposed to fit the aeroplane with one pair of eccentric running wheels so that when taking off, the front of the machine is raised and lowered. The wheels may be of elliptical shape mounted at the point of intersection of the major and minor axes.

456,632. *Landing Gear for Aeroplanes.* Aeroplanes Morane-Saulnier Societe Anonyme de Constructions Aeronautiques, 3, Rue Volta, Puteaux, Seine, France. Convention date (Germany), March 22nd, 1935.

In this retractable undercarriage, the wheel is carried by three struts connected to the aeroplane, one of which is jointed about the centre. When the jointed

strut is folded the chassis is retracted. The folding is carried out by a jack mounted on and carried by the jointed strut. It is positioned over the joint at right angles to the strut, one end of the jack forming a block to which the strut halves are hinged. The jack plunger is fitted with links engaging with pins on the strut halves some little way out so that when the jack is extended by admitting fluid under pressure the strut is folded and the chassis retracted. Various modifications in which similar jack arrangements are used for retraction are described.

455,384. *Improvements relating to Retractable Undercarriages for Aircraft.* Dowty, G. H., 17, Lansdown Crescent, Cheltenham, Gloucester. Dated April 23rd, 1935, No. 12,231, and May 25th, 1935, No. 15,307.

In this retractable undercarriage the jack carries a fixed member on which the part actuated by the jack moves. This member can be a structural part and four of the chassis members are anchored to the movable part actuated by the jack. On the jack being operated this member is moved along and in moving it carries the rest of the undercarriage to its folded position.

455,932. *Improved Means for Operating Aircraft Brakes.* Bendix, Ltd., King's Road, Tyseley, Birmingham, and Hall, P. E., of the same address. Dated May 15th, 1935. No. 14,178.

In aircraft brakes, where means are provided for steering on the ground as well as braking, it is proposed to use two hydraulic cylinders, or relay valves, mounted side by side with parallel axes in a casing. Rollers carried on pivoted links bear on the valves or plungers, and these are operated by a thrust member operating slideably between and opposite to the rollers. This operating member can be worked in a parallel direction, giving equal operation, or it may be moved sideways, giving differential operation.

456,139. *Improvements in Undercarriages for Aeroplanes.* Heller, M., 33, Burggasse, Vienna, VII, Austria, and Tippelt, A., 37, Grune Torgasse, Vienna, Austria. Dated May 3rd, 1935. No. 13,229.

The proposed arrangement consists in an auxiliary hollow lifting plane suspended from the aeroplane body by means permitting displacement of the plane relative thereto which is controlled by cushioning arrangements between the plane and the aeroplane itself. This plane may be fitted with boat bodies which serve as supports. It is also provided with frames fitted with wheels, endless tracks, or other alighting means, all of which are adopted, when bearing against a support, to maintain the auxiliary plane in its proper angular position.

454,279. *Improvements relating to Tail Wheels and the Like for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucester. Dated April 17th, 1935. No. 11,917.

This specification describes a retractable tail wheel. The fork carrying the wheel is supported resiliently and it can be retracted by angular movement about the axis of a bearing which forms the anchorage of the mounting. Further, the wheel and fork may be mounted pivotally for retraction by swinging about a preferably horizontal and transverse axis in the fuselage of the aeroplane and means for effecting the desired movements mounted on the unitary structure. Thus a jack used for this purpose is carried by the tail wheel structure.

AIRCRAFT CONSTRUCTION.

453,213. *Improvements in Resilient Connections and Joints.* D'Albay, J., 12, Rue Gustave-Dore, Paris, France. Dated Nov. 29th, 1934. Nos. 34,333 and 34,334.

This arrangement relates to resilient connections and joints where a resilient element made of rubber and arranged between two members movable relating to each other rolls without sliding when a displacement occurs between them. It is proposed that the opposed surfaces are not parallel at the place where the resilient rubber element has an oblong cross section so as to provide a device of variable flexibility. The resilient member is combined with others, the relative displacement of which not only cause the resilient member to roll, but also cause an increase of its diameter.

452,213. *Improvements in Aircraft.* Martin, J., Martin's Aircraft Works, Higher Denham, Uxbridge, Middlesex. Dated Feb. 18th, 1935. No. 5,172.

The proposed aeroplane is of monoplane type and has the engine mounted in the upper part of the fuselage. The occupants are seated in the forward portion of the fuselage and the engine shaft passing over their heads drives a tractor propeller. It is claimed that this arrangement permits easy access to the fuselage, protects the propeller and prevents the machine being tipped on its nose.

450,729. *Improved Structure of Wings or Other Parts of Aircraft.* Aeroplanes Morane-Saulnier Société Anonyme de Constructions Aeronautiques, 3, Rue Volta, Puteaux, Seine, France. Convention date (Germany), Aug. 21st, 1934.

The aeroplane wing structure proposed consists of a main spar and an auxiliary spar located some little distance apart, the first spar being attached by at least two points and the other attached at one point only. These two spars are connected together by a number of rigid members which are arranged in plan form, as in warren bracing. It is intended that the main spar takes the bending moment forces on the wing, while the auxiliary spar and the accompanying structure stiffen the structure in torque. Various modifications of the arrangement are described, some having the auxiliary spar and its bracing duplicated, there being an auxiliary spar on each side of the main spar.

451,241. *Improvements in or connected with the Construction of Wings for Aircraft.* Short Bros. (Rochester and Bedford), Ltd., and Gouge, A., Seaplane Works, Rochester, Kent. Dated Feb. 2nd, 1935. No. 3,443.

It is proposed to use a metal spar of approximately rectangular cross-section, and to mount within it a tank to contain, say, petrol. This tank can extend along the spar for a distance depending on the desired capacity, and the baffle plates in the interior of the tank are arranged to transmit loads within the spar itself by means of an external diaphragm web forming a continuation of the diaphragm in the tank and attached to the surrounding spar.

452,726. *Improvements in the Structure of Fuselages, Wings and Other Bodies of Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated Feb. 27th, 1935. No. 6,254.

This specification relates to the geodetic type of construction and it is proposed that both sets of the geodetic members are continuous from one longitudinal member to the next, they being recessed at each inter-section so that the two sets can fit into each other. Generally the geodetic members are of greater depth than width and in order that they may fit into each other they are recessed to half their depth, one from the inner edge and the other from the outer. At the intersection they are secured by means of riveted angle plates. Further, in the case

of a fuselage it is stated that it is advantageous to arrange one of the longitudinal members at the extreme top and one at the extreme bottom of the body and to arrange the remainder one at each side of the body in a plane at right angles to that containing the upper and lower members.

452,516. *Improvements in or relating to the Reinforcement of Stressed Skin Structures such as Monocoque Fuselages, Hulls, Wings and the like Components of Aircraft.* Gerard, I. J., Heath Ridge, Shortheath Road, Farnham, Surrey. Dated Feb. 28th, 1935. No. 6,404.

In the case of hollow metal structures with smooth external surfaces it is proposed to stiffen these surfaces with internal tubular stiffness. These may be of any desired section, circular, square, etc., and they may be tapered. They may be attached by rivets, spot welding, etc. They may be formed separately or formed integrally with the sheets.

AIRSCREWS.

452,282. *Torsional Vibration Absorber.* G. and J. Weir, Ltd., Holm Foundry, Cathcart, Glasgow, and Bennett, J. A. J., of Genista, Newton Mearns, Renfrewshire. Dated Oct. 1st, 1935. No. 28,392.

In order to reduce the amplitude of torsional vibrations in propellers, it is proposed to use a propeller wherein link means pivoted to the shaft about an axis perpendicular to the shaft are connected to each blade by a pivot whose axis is skewed relatively to the shaft axis and wherein the projections of both said pivot axes on a plane at right angles to their common perpendicular enclose an acute angle, the length of the link means being small relative to the radius of gyration of the blades.

455,688. *Propulsion Means for Watercraft and Aircraft.* Sanders, C., Bolderweg 59, Derr Hdder, The Netherlands. Convention date (Holland), Jan. 20th, 1934.

This specification describes a flapping blade propeller which is arranged symmetrically about a longitudinal axis, the blade having a flapping movement about a transverse axis, a lateral tilting movement or these movements simultaneously.

454,983. *Improvements in or relating to Aircraft and Propulsion Means Therefor.* de Havilland, G., and The de Havilland Aircraft Co., Ltd., Hatfield Aerodrome, Hatfield, Herts. Dated July 9th, 1935. No. 19,636.

In the case of airscrews for aircraft it is proposed to combine the use of variable pitch airscrews with a variable speed gear, so that the speed ratio between the engine and propeller can be varied as well as the propeller pitch. It is proposed to use a high gear when the propeller blades are at a low pitch and a low gear when the blades are at a relatively high pitch.

AUTOGIROS.

452,364. *Improvements in and relating to Aircraft with Autorotative Wings.* J. de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Jan. 16th, 1935.

This specification relates to the well-known autogiro and is concerned with various expedients for controlling and regulating the rotor blade pitch angle, the devices for this purpose falling into two groups. In the first the pitch angle is positively regulated by mechanism independent of the forces on the blade or manually by the pilot, in which case the control will be rendered at least semi-automatic. In the second the pitch angle is controlled in a fully automatic manner in accordance with the balance of forces experienced by the blades themselves.

452,365. *Improvements in and relating to Aircraft with Autorotative Wings.* J. de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Jan. 16th, 1935. No. 1,547.

This specification is concerned with autogiros in which the pitch regulating mechanism of the rotors is automatically regulated. The object of the mention is to minimise the risks attendant on an unintentional take-off should the engine stop or slow down, which would cause a sudden increase of pitch in a rotor with automatic pitch control. Also, if in the air the engine torque picks up, a sudden increase of torque would take place which would reduce the pitch and cause the machine to fall heavily.

452,397. *Improvements in and relating to Aircraft with Autorotative Wings.* J. de la Cierva, Bush House, London, W.C.2. Dated Jan. 16th, 1935. No. 1,347.

This specification relates to means for destroying the lift of the wings on the machine alighting on land or water. The means for this purpose may be actuated by contact with the ground, water or otherwise, by decreasing the pitch angle of the rotor.

452,366. *Improvements in and relating to Aircraft with Autorotative Wings.* J. de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Jan. 16th, 1935. No. 1,548.

This specification relates to autogiro blades particularly adapted for obtaining the best direct take off. For this purpose the minimum drag of the wing must be as low as possible, hence the solidity of the rotor should be very small and the blades should taper towards the tips. The blade is also to have a non-uniform section so that a small portion of the blade has a stable pitching moment and the rest of the blade has an unstable pitching moment, these parts being so proportional that the overall pitching moment of the blade is substantially neutral.

452,922. *Improvements in or relating to Power Transmission Mechanism for Aircraft.* Yoxall, York House, Deganwy, North Wales, and Propello Inventions, Ltd., 105, Cheyne Walk, Chelsea, London. Dated Feb. 1st, 1935. No. 3,388.

This device is intended for use in driving the rotor of a gyroplane from the engine. It is stated that it is undesirable to accelerate these rotors with the aid of slipping clutches and it is proposed therefore to interpose between the engine and the rotor a mechanism comprising a fluid flywheel, hydraulic coupling or torque connector having two or more members relatively and individually rotatable combined and arranged with change speed gearing of any type (e.g., countershaft, epicyclic infinitely variable) to operate between the engine and the rotor.

452,407. *Improvements in and relating to Aircraft with Autorotative Wings.* Juan de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Jan. 16th, 1935. No. 18,394.

This specification refers to autogiros incorporating rotor blade pitch controlling devices of an automatic type when the pitch amplitude is controlled by the balance of forces in the rotor blades themselves. It is proposed to provide automatic means for causing the blades to assume a pitch angle less than that obtaining in normal flight on the application of a braking force to the rotor. One method consists in arranging for a pitch reduction when the blades move forward. There is a compound articulation in place of the drag point which consists of two independent pivot axes, one being inclined upward and outward with respect to the blade axis, and the other is inclined upward and inward with respect to the blade axis, arrangements being made that the displacements are small, and that the displacements about the axes shall take place in succession.

456,177. *Improvement in or relating to Aircraft Provided with Rotating Wings.* Jones, T., Cwmbach, Pontyates, Llanelly, Carmarthenshire. Dated July 9th, 1935. No. 19,602.

This arrangement consists of a shaft carrying aerofoils revolving in bearings fixed in direction with respect to the fuselage axis and parallel thereto and set at a small positive angle. It is stated that under these conditions the shaft with aerofoils will rotate. Two such rotating arrangements may be used.

BOMBS AND BALLISTICS.

454,078. *Improvements in Aerial Floating Mines for Defence against Aeroplanes.* Tinssonier, Le Plissay, Olivet (Loire), France. Convention date (France), April 17th, 1935.

This specification describes a type of balloon which is intended to carry a charge of explosive to a certain height and then to descend. Explosion takes place if they come in contact with aircraft, otherwise they descend without exploding. The balloon consists of a system of lobes which is capable of expansion at high altitudes. This expansion is utilised to operate an arrangement which deflates the balloon when the predetermined height is reached.

CONTROL OF AEROPLANES.

451,469. *Improvement in or relating to the Supporting Surfaces of Aeroplanes.* Lumiere, H., 96, Cours Albert Thomas, Lyons, France. Convention date (France), Jan. 19th, 1935.

In the case of aeroplanes fitted with flaps or split flaps to the inner portions of the wing for the purpose of increasing lift, it is proposed to arrange additional flaps in the fore and aft directions at the outer extremity of the wing flaps. These additional flaps can be opened to 90°, are opened with the wing flaps, and are for the purpose of canalising the air flow between themselves and the sides of the fuselage so as, it is stated, to increase the lift of the flapped portion of the wing.

450,676. *Improvements in and relating to Aeroplanes.* Irving, H. B., The National Physical Laboratory, Teddington. Dated Nov. 22nd, 1934. No. 33,632.

In order to produce an aeroplane wing with increased stability in roll it is proposed to use a biplane having two wings of approximately the same span, arranged so that the gap between them decreases to a small value from the centre to the tip. The trailing edge of the upper wing is near the leading edge of the lower wing. To attain this, any arrangement of dihedral angles between the planes may be used. Either or both wings may be tapered, the upper having the greatest taper, or they may be swept backwards or forwards.

455,462. *Improved Aeroplanes.* Societe des Aeronefs Miquet, 11, Rue du Palais, Meaux, Seine et Marne, France. Convention date (Belgium), April 26th, 1935.

This is a modified elevator control intended for aircraft of the " Pou " type in which arrangements are made so that the incidence of the rear wing may be altered in conjunction with the front wing so as to give improved control. A cam arrangement is used so that the incidence of either wing can be varied independently or together and in the desired proportions and over the desired range of angle.

455,501. *Improvements in or relating to Aeroplanes and the Like.* Nazir, P. P., Marlow, Petersham Avenue, Byfleet, Surrey. Dated April 15th, 1935. No. 11,994.

In order to improve control, especially near the stalling point of an aerofoil, it is proposed to use a wing having a normally closed slot towards the rear,

the slot being parallel with the span. The upper and lower surfaces are connected by a plate associated with the slot which is movable to project downwardly and rearwardly from the wing to give auxiliary lift and, in so moving, to open the slot. The plate can also be made to project above the wing and to increase the drag.

454,490. *An Improved System for Controlling the Evolutions of an Aircraft.* Societe d'Inventions Aeronautiques and Mecaniques S.I.A.M., 1, Route des Alpes, Fribourg, Switzerland. Convention date (France), April 11th, 1934.

This is a device for controlling the evolutions of an aircraft by means of a surface moving with said aircraft and subjected to the reaction of the medium in which it moves, of the kind in which said surface is subject to an effort exerted thereon by a gas under pressure, the degree of which is controlled by the pilot.

453,928. *Automatic Steering Arrangements for Air and Water Craft.* Siemens Apparate und Maschinin Gesellschaft mit Beschrankten Haftung, 4, Askanisher Platz, Berlin, S.W.11, Germany. Dated Dec. 14th, 1934. No. 35,962. Specification not accepted.

It is proposed to use an automatic steering arrangement comprising a main steering surface such as a rudder or a damping surface for the trim compensation of aircraft, adapted to be controlled through an auxiliary steering surface by means of the relative flow in combination with automatic steering means, the arrangement being such that the direction finder of the automatic steering means is connected to control an auxiliary motor, which in turn acts on the auxiliary steering surface to vary the position thereof.

456,144. *Improvements in and relating to Motion Transmitting Mechanisms, Particularly for Use in the Actuation of Control Surfaces of Aircraft.* Collar, A. R., National Physical Laboratory, Teddington, Middlesex. Dated May 3rd, 1935. No. 13,283.

This mechanism includes an epicyclic or hypocyclic gear characterised in that the gear is arranged so that the plant pinion is caused to rotate about a stationary gear wheel, and a link is connected to some fixed point on the pinion so that when this point is at a cusp in its path or when it moves at right angles to the direction of the link the other end of the link provides a dead centre at some point intermediate between the ends of the stroke of the operated mechanism.

455,721. *Improvements in or relating to Wings or Control Surfaces for Aircraft.* Dr. Ing. E. Heinkel, Serstrasse 15, Warnemunde, Germany. Convention date (Germany), July 17th, 1934.

The proposed wing has two or more sections connected together, adjacent sections along adjacent edges having spars. The connections joining the sections are designed to transmit load from one to the other. There are also covering members for concealing the gaps which are inserted between the edges of the outer covering so as to avoid gaps. It is claimed that this construction facilitates manufacture, and that the multiplicity of spars minimises bullet damage.

ENGINES.

451,849. *Improvements in or relating to Power Producing Means for Ships and other Craft.* Kreasel-Williams, G. H., Calle-Corrientes 345, Rosario de Santa Fe, Argentina. Dated Jan. 7th, 1935. No. 509.

It is proposed to employ means for ships and other craft for producing power by providing a motor adapted to be operated by the fluid flowing past the craft. This may be utilised for assisting propulsion or for generating electric current,

etc. The fluid motor proposed consists of a screw shaped member rotating inside a venturi, the external form of the screw being shaped to the interior of the venturi.

451,525. *Improvements in Cowlings for Air-Cooled Internal Combustion Engines for Aircraft.* The Bristol Aeroplane Co., Ltd., Fedden, A. H. R., and Mayer, F., all of Filton House, Bristol. Dated May 21st, 1935. No. 14,859.

It is proposed to arrange a movable flap on each side of a N.A.C.A. cowling for an aircooled engine. When it is desired to increase cooling, these flaps, which are hinged on their front edges, are swung outwards. In order to permit the engine accessories which are mounted at the rear of the engine to be inspected or serviced, arrangements are made so that these flaps can be swung out still further, so that the accessories can be reached through the aperture so provided.

451,577. *Improvements in Flexible Mountings for Aircraft Engines.* Paulsen, J. F., 6, Rue Francois Gaillard, Viroflay, Seine et Oise, France, and Strachovsky, N., 31, Rue le Mariro, Paris, France. Dated Dec. 1st, 1934. No. 34,528.

The arrangement proposed comprises a flexible engine mounting in which there is a plate member attached to the engine, and a plate member attached to the engine supports. These have flat surfaces perpendicular to the crankshaft. The flat surfaces are bonded together with resilient material. The engine is supported solely through resilient material in shear. Another resilient mounting is proposed in which there are a number of members connected to the engine, and a number connected to the engine support. These are bonded together by resilient material so that the abutting pieces of the resilient material lie in planes at right angles to the crankshaft.

451,296. *Improvements in or relating to Cooling Arrangements for Radial Cylinder Internal Combustion Engines for Aircraft.* The Bristol Aeroplane Co., Ltd., Filton House, Bristol, and Fedden, A. H. R., Filton House, Bristol. Dated March 22nd, 1935. No. 9,011.

In an air-cooled radial engine having a cowl of the shape of that known as an N.A.C.A. cowl with the exhaust ring found in the leading edge of the cowl, it is proposed to arrange a partition behind the exhaust ring and between it and the cylinders so as to divide the oncoming air stream into two sections, an inner which cools the cylinder, and an outer which cools the exhaust ring. The air heated by the exhaust ring may be discharged through conduits inside the cowl, which conduits may also contain exhaust pipes, or this air may be discharged through the periphery of the cowl.

455,248. *Improvements in Cowls for Air-Cooled Aircraft Engines.* Bristol Aeroplane Co., Ltd., Fedden, A. H. R., both of Filton House, Bristol, and Copley, J. W., 44, Norton Road, Knowle, Bristol.

This proposed cowl has a number of movable flaps at its trailing edge so that the rate of airflow through the cowling may be adjusted. The flaps are hinged about axes which lie on the chords of a transverse cross section of the cowl, and are arranged to be spread outwards so as to increase the cross sectional area of the annular orifice between them and the aircraft body.

454,664. *Improvements in or relating to the Cooling of Aircraft Engines.* de Havilland, G., and The de Havilland Aircraft Co., Ltd., Hatfield Aerodrome, Hatfield, Herts. Dated April 24th, 1935.

It is proposed to use an enclosed compartment containing the parts of the engine requiring to be cooled, to which air is fed from openings located in the

wing, in a position of positive air pressure, the outlet from the enclosed compartment being situated in a region of low air pressure. In one example it is proposed to locate the inlet openings at the leading edge of the wing.

454,753. *Improvements in and relating to Aeroplanes and Flying Machines.* Aeroplanes Morane-Saulnier Societe Anonyme de Constructions Aeronautiques, True Volta, Pateaux, Seine, France. Convention date (Germany), Jan. 26th, 1935.

It is proposed to mount wing engines in aircraft by attaching them to the front of the front spar of the wing and supporting them by bracing. A horizontally opposed multi-cylindrical engine is preferred as it does not project over or under the wing. The cowling used in this case is of similar shape to the nose of a wing.

456,674. *Improvements in the Mounting of Radiators of Internal Combustion Engines Used in Aircraft.* Cowdray, C., 4, The Nook, Derby Road, Chelaston, Derby, England. Dated June 27th, 1935. No. 18,418.

It is proposed to mount the radiator of a liquid cooled engine directly on the crankcase and below the engine itself. The engine has four special lugs cast on the crankcase to each of which the apex of a triangular shaped member is attached with a bolt cushioned with rubber. The bases of the triangular members are attached to the radiator, also through cushioned connections. The rear triangles are deeper than the front ones so that the placing of the radiator conforms with the shape of the engine cowling.

456,702. *Device for Controlling Aircraft Motors.* Ruspoli, E. A., 19, Avenue Rapp, Paris 7, France. Convention dates (France), Jan. 22nd, 1935, and Oct. 14th, 1935.

This is a device for ensuring that all the engines of a multi-engined aeroplane rotate at the same speed, and the control depends on the frequency of an alternator, which may be driven either by an accumulator and electric motor or by one of the aeroplane engines concerned. The throttle controls of the controlled engines are governed by a differential regulating device subjected to the difference between the actual speed of the motor and that corresponding to the frequency of the synchronising current.

456,335. *Improvements in Radiator Cowling for Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby. Dated April 3rd, 1935, No. 10,418, and April 16th, 1935, No. 11,761.

In the case of radiators for fluid-cooled engines it is proposed to vary the air flow through the radiator by means of a flap at the rear of the tunnel enclosing the radiator. The flap is hinged at its forward end and is hinged to the radiator tunnel at the part of the tunnel remote from the fuselage.

454,266. *Improvement in or relating to Aircraft and other Craft or Vehicles.* Stewart, C. J., and Meredith, F. W., both of Royal Aircraft Establishment, South Farnborough, Hants. Dated March 28th, 1935, No. 9,704, and Jan. 13th, 1936, No. 1,113.

It is proposed to raise the kinetic energy of the air stream at its discharge from a duct by transferring to it waste heat from the engine at a position behind the cooling surfaces and before further loss of pressure is sustained beyond that involved in passing the stream over the cooling surfaces. The heat of the exhaust gases may be discharged into the stream. It is stated that in aircraft travelling at about 300 m.p.h. the resistance of the cooling arrangements may be much reduced by this scheme and that it may even produce a thrust.

FLUID MOTION.

456,063. *Methods of Creating a Force by Discharging a Pressure Fluid into another Fluid under Lower Pressure.* Societe Anonyme d'Etudes des Brevets et Procedes Counder, Societe Counder, 10, Rue Bardin, Clichy (Seine), France. Convention date (France), Oct. 8th, 1934.

It is stated that if a narrow slot is arranged at one side of a suitably curved surface, an issuing stream of fluid under high velocity will be caused to follow this curved surface, causing a depression in front of the body and causing it to move forward.

HELICOPTERS.

452,880. *Improvements in Aeroplanes.* Shamberger, G. A., Box 62, Rural Free Delnery, Route No. 1, Town of Shaw, Marion, Oregon, U.S.A. Dated May 3rd, 1935. No. 13,189.

It is proposed to construct an aeroplane having a helicopter-like mechanism for breaking the landing speed to permit the machine to ascend or descend substantially vertically to the ground and to safely descend should the usual straight away motor and propeller fail. The pair of helicopter propellers are mounted in suitable openings through the wing of an aeroplane, said openings being closed for straight ahead flights and while the helicopter propellers are not in use, and a separate engine, or means connected to the usual engine for driving the said propellers.

KITES.

455,067. *Aeroplane Kite.* Trevor, A. H., 1802, South Tower, Seattle, King, Washington, U.S.A. Dated Dec. 30th, 1935. No. 35,968.

The proposed kite is in the form of a biplane aeroplane of normal type, the wings being flexible permitting upward bowing in accordance with wind pressure, and with means whereby the upper wing frame may be adjusted. The kite has a strong propeller and it is stated to be automatically stable.

MISCELLANEOUS.

456,076. *Improvements in and relating to Aerial Posters.* Air Publicity, Ltd., Shell Mex House, London, W.C.2, and Macleod, L. S., Bonbe Buildings, 24, Bramley Hill, Croydon, Surrey. Dated June 21st, 1935. No. 17,858.

This is a streamer towed from aircraft carrying advertising matter. The letters are made up on fabric skeletons and the intermediate struts are disposed in pockets on the leading edges of the letters. These struts keep the towing tapes apart and the letters displayed. The tapes are sewn to the letters. The whole arrangement is loaded or otherwise arranged to be vertical in flight and there may be a blank tail section to maintain steadiness. It is claimed that the letters can be readily changed and that the openwork construction assists legibility.

SEAPLANES.

452,989. *Improvements in Seaplanes, Flying Boats and the like.* Plunkett, D. L., 22, River Court, Portsmouth Road, Surbiton, Surrey. Dated March 29th, 1935.

This specification describes a float for seaplanes which is collapsible and which can be folded into the aeroplane wing. The float itself consists of a collapsible bag which covers a frame. This frame is supported by front and rear members which are hinged to the frame and to the wing so that the float is retractable by parallel link motion of the strut members.

REVIEWS.

THE THEORY OF DIMENSIONS AND ITS APPLICATION FOR ENGINEERS.
By F. W. Lanchester, LL.D., F.R.S., Hon. F.R.Ae.S. Crosby, Lockwood and Son, Ltd. Price 12/6.

The importance of the theory of dimensions to the engineer is not reflected in the literature on the subject. Although most engineers use the method for the analysis of formulas and for the solution of problems, it is probable that many of them do not fully realise the implications of the theory and do not appreciate how powerful the method can be in skilled hands.

Dr. Lanchester's book deals with the subject in an unusually interesting manner. It not only describes logically and clearly the meaning of dimensions, but proceeds to give several interesting examples of their application to engineering problems. There is a section of the book devoted to that controversial subject, the dimensions of electrical units, in the course of which the author makes use of the theory of relativity, possibly the first time this theory has been used to shed light on the practical problems of the engineer.

Apart from these matters there is a very able analysis of the various units in common use, on which the slug as a unit comes in for considerable criticism. There is no doubt that the poundal is the only rational unit of force in English units for scientific purposes, but practically, the use of the slug for aerodynamical calculations saves a slide rule operation, thus dividing by 32.2. But Dr. Lanchester's theoretical objections to the slug are unquestionably valid, and it is well that those who use it should realise exactly what it is.

Apart from these matters there is a collection of physical constants towards the end of the book which have been carefully checked by the author and there is also a chapter on the calorific value of fuels. In both cases there is much of interest in the reading matter.

Dr. Lanchester's great gift is the power of seeing a little further and a little clearer into matters than the normal engineer, with this he combines a literary style which is always easy to read. We, of the aeronautical community, owe to him the first exposition of those aerodynamical theorems which have since, unfortunately, become known under the name of Prandtl. This, his latest work, is a book of real importance to all engineers.

MATHEMATICS FOR THE MILLION.
Lancelot Hogben. George Allen and Unwin, Ltd. 1936. 12/6.

I recommend this book, firstly, to all those who believe they can teach mathematics from simple arithmetic to the arithmetic of human welfare. Secondly, I recommend it to all those who have found mathematics difficult or not to their liking, for here is a book which simplifies, exemplifies and testifies to the real usefulness of a subject for which the general majority of the world have no use whatever.

Professor Hogben has written a book which is outstanding in its merits, for it is a book which interests, elevates and amuses, a book of wide learning and shrewd teaching. It will be quoted widely for its many (not to be taken too seriously) comments on life in general as well as mathematics in particular. Mathematics for the Million is a partial history of the subject and a very clear exposition of just those very things which made life so difficult for budding

mathematicians who never burst into full flower a generation ago. The titles of the chapters themselves are a clue to the treatment, " Euclid without tears or what you can do with geometry," " From crisis to crossword puzzles or the beginnings of arithmetic," and " The dawn of nothing or how algebra began." Laughter and tears go often hand in hand and Professor Hogben has combined with uncanny skill the tears of hard learning with the laughter of easy remembrance. Once one has read through this book he will have acquired, almost in a way unknown to himself, a knowledge of mathematics up to the calculus. The reviewer may have given an impression that it is a book which is rather flippant. The very contrary is the case. It is the most serious book on mathematics written in our generation, because it is a book which will go a long way towards revising the attitude of many people towards mathematics. For here the real use of the subject is explained and exploited on almost every page.

I cannot refrain, however, from quoting, " General mathematics was not financed by the Air Ministry like modern aerodynamics."

" Nothing would do more to promote a rapid advance in human understanding than an annual conference between school boys, school masters and elderly scientists. The scientists should be compelled to attend under pain of losing their pension rights."

" Some of us decide we are stupid and acquire a distaste which makes the subject unnecessarily difficult. Others (the bright ones) accept what they are told with becoming humility, and stop examining the implications of the scientific outlook on the world. Later on they become professors."

Mathematics for the Million is an outstanding achievement.

MARTIN'S AIR NAVIGATION.

By C. W. Martin. Pp. 265. The Eversley Press. 1936. 21/-.

This book gives an excellent account of air navigation, which is suitable not only for those taking the navigator's licences, but also for anyone interested in this branch of flying.

It is, indeed, fortunate that Mr. Martin has found time to write this book for those unable to attend his classes. Previously it was necessary to refer to many books, which either contain irrelevant material, or which are difficult to understand. Neither of these criticisms apply to Martin's " Air Navigation." All superfluous material has been omitted, and the wording is exceptionally clear—it might almost be said that Martin has used " Basic English." In this direction, the words involution and evolution (p. 23) might possibly be omitted, and the term " bearing " used in place of " azimuth " (p. 128). Although " azimuth " is more strictly correct, most pilots understand the meaning of the word " bearing " from *D/F* work.

On the top of p. 145, it might be possible to mention that starboard drift on a flight will give a high reading of the altimeter at the destination.

The author will no doubt consider the simple method of interception mentioned in *Flight*, November 26th, 1936 (written after the book was published), for future editions.

Further, the Dalton Course and Distance Calculator, also recently available, might be mentioned in future editions, as a simple instrument for working out *D/R* problems quickly and accurately.

Amongst the methods given for obtaining the wind during flight (pp. 201 *et seq.*), the summer (reciprocal course) method might have been included.

It is a pity that the author decided not to include a few hints on signalling, similar to the excellent suggestions for drawing a weather map (p. 139).

A bibliography and index would be useful, without taking up much space.

These minor criticisms must not be taken as a condemnation. The book is excellent, and is just what the " B " Licence pilot needs. Never before have the principles of navigation been expressed so clearly and simply, and yet so accurately.

SMALL FOUR-STROKE AERO ENGINES.
By C. F. Caunter. Published by Sir Isaac Pitman and Sons, Ltd. Price 6/-.

This is a book belonging to a type in which Mr. Caunter specialises. It is not highly technical, but it contains a quantity of useful information on its subject written in a manner which is easy to read. It seems probable that he has contrived to obtain some information about every small aero engine in existence, and he certainly mentions several whose details are not to be found elsewhere.

The book starts with a general account of some small aeroplanes in which the engines he talks about could be used, and in discussing their practical uses, he compares their speeds with those of motor cars, frankly admitting that in doing so he has disregarded head winds. But in doing so, he has disregarded a factor of great importance in this connection for, adding a normal and usual head wind, there are several small aeroplanes which are not much faster than a fast car. Again, on page 9 he refers to miniature aeroplane running costs as approximately 1½d. per mile inclusive. It is extremely doubtful whether this figure could include such important items as insurance, depreciation, housing costs, etc., and in any case, unless it really includes all costs, those which are left out should be mentioned.

Apart from this subject and the descriptions of the engines themselves, there is also a general account of methods of maintenance and of types of engine accessories and of the way they are usually driven. The whole forms a useful book of reference.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—The article in the November number of the JOURNAL on "Mixture Strength in Petrol Engines," by G. D. Boerlage and L. A. Peletier, quotes from Landolt and Börnstein Tables that the thermal conductivity of oxygen is equal to that of nitrogen. Later the authors calculate a value of 99.3 for nitrogen compared with 100 for air. The International Critical Tables give nitrogen as 104 on the same basis. For calculations in connection with electrical exhaust gas analysers the relative thermal conductivities of dilute mixtures are of much more importance than the thermal conductivities of the pure gases. The following table showing the relative effects of 1 per cent. by volume of the gas in atmospheric nitrogen may therefore be of interest. The ratios were taken with a Shakespear katharometer and are substantially correct over the range of concentrations found in exhaust gases:—

Carbon dioxide, CO_2	10.4
Carbon monoxide, CO	1.2
Oxygen, O_2	−1.8
Methane, CH_4	−10
Water vapour, H_2O	−12
Hydrogen, H_2	−100

These figures give the thermal conductivity of atmospheric nitrogen as about 98.7 and oxygen about 105 compared with air 100.

Yours faithfully,
G. JESSOP, *Chemist*,
Cambridge Instrument Company, Ltd.

18th Dec., 1936.

The 610th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

An Ordinary Meeting of the Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 12th, 1936. In the chair, Mr. H. E. Wimperis (President of the Society).

The PRESIDENT: Before calling upon Dr. Lanchester to give his lecture he had an announcement to make to the members which was of a very agreeable character. It would be remembered that some years ago the Society received sums of money from the Guggenheim Fund which made it possible to extend the activities of the Society in various very useful directions, but, under circumstances over which none of them had any control, the source of that benefaction came to an end, and the increased activities to which he had referred, such as improvements in the JOURNAL, had to be kept going without the assistance of the moneys in question. Recently the Council had been looking into the position and came to the conclusion that a rather larger income would be agreeable, and he was pleased to be able to announce that two of their members—Mr. Handley Page and Mr. Fairey—had most generously decided between them to add £750 per annum for the next seven years to the Society's funds which they considered would fill the gap between current income and current expenditure. As a result of what he had just announced the Society would be able to maintain and, it was hoped, improve the facilities offered to its members both as regards the JOURNAL and in other ways. The Council of the Society on learning of this had, of course, passed resolutions of thanks and were conveying their appreciation personally to Mr. Handley Page and Mr. Fairey. The President added that he thought he would like to tell the members about this so that they might share the Council's delight on hearing of it at the last Council meeting a few days ago.

The meeting expressed its appreciation by a round of applause.

The PRESIDENT: Dr. Lanchester, the lecturer that evening, was a Fellow of the Royal Society and an Hon. Fellow of the Royal Aeronautical Society, and, of course, was well known to all the members. The world had had its prophets and, for the most part, its prophets were no longer with us, but aeronautics was very young and he was glad to say that they had one of their prophets—a major prophet—still in the flesh, and he was going to speak to them that evening. Dr. Lanchester, of course, was not going to read his paper in full, but he had suggested to Dr. Lanchester that in reading his abstract he should fulfil the *rôle* of prophet and tell them of the future as well as of the past and say where his conclusions were likely to lead in aviation.

THE PART PLAYED BY SKIN-FRICTION IN AERONAUTICS.

By F. W. Lanchester, LL.D., F.R.S.

Part I.

Historical and General.

The early work of Froude. Relation of skin-friction to resistance arising from other causes. The Langley fallacy. The Reynolds Number and the condition of laminar flow: expressed graphically. Resistance as a function of velocity. Ichthyoid or streamline bodies: exemplified in the Graf Zeppelin airship, etc.

§1. It is now almost thirty years since the author published his "Aerodynamics"* and more nearly forty years since he first made use of the teaching of William Froude, and adopted skin-friction as a basis on which to compute direct resistance in connection with aeronautics. It was many years before this doctrine became generally accepted, namely, that *under the most favourable conditions*, direct resistance, whether it be that of the body of an aeroplane or an airship, or that of the aerofoil or wing members, is dependent upon skin-friction just as in the case in a sea-going vessel.

If we read the literature prior to the time of William Froude we find theories of ship resistance according to which the skin of the hull was regarded as being made up of a number of component planes, and the resistance as due to the sum of these. Even when Froude had shown that (apart from wave-making) the resistance of a *well-designed* hull could be computed on the understanding that the resistance was wholly due to skin-friction, there were others who still talked of *form* resistance as additional to skin-friction, and so it came about that some little time elapsed before Froude's teaching triumphed. And still there is that expression "well designed." It is necessary because a badly-designed hull may give rise to resistance of another kind altogether. As the author once had occasion to point out, Froude's rule will not apply to a coffin or a beer barrel afloat.[1] It is easy thus to specify forms which considered as vessels will give rise to more resistance than that due to skin-friction, the point is that it is not possible to design a form which will give rise to less. Then the physicist might ask, how can the best form under any given conditions be reached? The reply is that to the naval architect the difference between a well-designed hull and one badly designed was familiar before Froude's day; forms had been developed by experience and trial and error, of which the resistance differed but little from the best possible; by the use of an experimental tank (a creation of that same William Froude) the process of trial and error is expedited, and much time and money saved. The recognition of skin-friction as the prime cause of direct resistance proved of inestimable value.

§2. It was again Froude who, if not the first, was amongst the first, to measure skin-friction by towing planks of various lengths through the water at different speeds, with surfaces of varying roughness, in order to provide quantitative data for the ship designer and builder, and who laid it down that *the resistance due to skin-friction could be computed as equal to that of a plane or plank of the same length as the vessel's water-line, and presenting to the water the same*

* Where reference is made to "Aerodynamics" it is to be understood as the author's work (published by Constable & Co.).

[1] Proc. Inst. Automobile Engineers, Vol. IX, pp. 243 and 253.

area of wetted surface. He was aware and did not disguise the fact that projections or excrescences, if any (such as the propeller brackets in the modern twin screw vessel), must be taken into account as something additional.

Now it should have been clear to anyone acquainted with the subject that Froude's work could be applied directly to aircraft of every kind, and that very important consequences would result from its application. In his early model experimental work the author was guided by this conclusion and made many endeavours with crude and makeshift apparatus to determine the magnitude of the frictional constant or coefficient in air. One of the first obstacles was to dispose of the false doctrine propounded by Langley that *skin-friction in its relation to flight is negligible*. In spite of the author's careful examination of this fallacy and his pointing out exactly how Langley had fallen into error, the error persisted, and in some quarters the author believes it persists (perhaps a little toned down) even to this day.

This then will be the " take off " point for the discussion.

§3. The author by no means denies the existence of " form resistance." Every body of uncouth shape in its passage through a fluid sets up eddies and leaves in its wake a condition of turbulence; his view is that, as disclosed in his work, there is a complete analogy, in fact identity, between the conditions in air and water and Froude's thesis applies to the one as to the other. Concerning Langley's experiments and the views held by him, and by many that followed him, a point of some subtlety arises, namely, the interdependence of form resistance and skin-friction. This point has been discussed fully by the author on several occasions,[2] it is, therefore, only necessary to make brief reference to it here. The planes used by Langley were flat plates of wood with perfectly square edges, the thickness being about 1/8 inch for a plane of from four to twelve inches width (in the line of flight). This form was adopted deliberately because Langley considered that to adopt a " faired " form which did not present flat surfaces to the " wind " might lead to unknown error; he, with true scientific precision of thought, was concentrating his attention on *planes*, and his intention was of the best: he thought that the edge resistance could be separately computed, and due allowance made. In this he was unconsciously falling into the same old error; the truth is that even in the most simple and elementary cases the component surfaces of a body cannot be taken as acting independently. In the case in point, the air set in motion by the bluff leading edge relieved the following surfaces of skin-frictional resistance, in other words, the resistance was transferred from the upper and lower surfaces to the leading edge and the resulting total was not the sum of two independent resistances as Langley assumed, but the greater of two alternatives.[3] A similar condition arises in the case of a railway train. Although streamlining for a motor vehicle or a single rail coach is most beneficial, it is far less so with a lengthy train; in such a case, except when there is a side wind, streamlining may be of comparatively small value. When the entry or " cut-water " of the locomotive is formed to disturb the air as little as possible, then the sides of the train are subject to the full effect of skin-friction. When, on the other hand the entry is bluff, the air that washes the surfaces of the coaches is already in motion and skin-friction is relieved. In popular phraseology the bluff entry acts as a pacemaker to that which follows; it is well established that when a cyclist is " paced " by a motor vehicle fitted with a vertical screen, he is actually sucked along, the skin friction and other direct resistance becomes negative; the following wake is in more rapid

[2] " Aerodynamics," §§158, 234 *et seq.* Also Paper contributed to the San Francisco Congress 1915; Part II, see reprint " The Flying Machine from an Engineering Standpoint," p. 115, Constable, London. Also Proc. Inst. Automobile Engineers, Vol. IX, pp. 242 *et seq.*

[3] Perhaps somewhat augmented: see " The Flying Machine from an Engineering Standpoint," Constable, London, p. 118.

forward motion than the vehicle by which it is caused. This is an extreme case but it is nevertheless a condition not to be forgotten.[4]

§4. This leads us to consider the peculiar case of the truly *plane* aerofoil, on the face of it this should be vastly inferior to the curved or cambered form, and yet in the case of models of small dimensions it shows little or no inferiority.[5] The reason for this undoubtedly is that in small gliding models the skin-friction is a more important matter than in those of larger dimensions and the upper surface of a ballasted plane in flight is not " washed " by the air stream; there is what is commonly called a dead-water region, and the upper surface is actually in the return current of a vortical disturbance occupying this region and is thus helped rather than hindered by the surface friction. This compensates in some degree for the " uncouth " shape[6] which otherwise would render a plane vastly inferior economically to a form of curved or cambered section, the basis of comparison being the gliding angle. The author believes that this is the reason why nature no longer makes use of the cambered wing section when working on a small scale, in brief, it is the reason for the marked difference in the flight organs and mode of flight exhibited as between birds and insects.[7]

§5. Of recent years some advance has been made in the scientific investigation of skin-friction, we hear talk of the " boundary-layer " and the condition of laminar flow and turbulence, but, so far as the practical problem of flight is concerned, our knowledge has made very little advance in the last thirty years. In Vol. I of the author's " Aerial Flight "[8] he showed that the conditions as between air and water were strictly comparable, and deduced and applied the dimensionless criterion LV/ν, now known as the " Reynolds number," used for the co-relation of experimental data. In that work and later in 1915[9] he quoted the work of Froude as applicable to skin-friction in the case of air as in that of water. Furthermore, he gave the law of laminar flow $P \propto V^{1.5}$ as the result of a simple investigation conducted on dimensional lines.[10]

Froude himself did not make use of the dimensional method, that potent weapon was but little known in his day. But he had his sure instinct to guide him, and lost nothing on that account by being before his time. Dimensional reasoning and the application of the Reynolds number presuppose *strict geometrical similarity*, and this condition was not complied with by Froude in his investigation of skin-friction; but with that intuitive insight which is given to the few, he reasoned that the only linear quantity which mattered was the length of the experimental plane *in the line of motion*. This, though infringing the condition of geometrical similarity, is even to-day regarded as being justified, though modern research workers would usually prefer to maintain the strict rule.

§6. Under the conditions which mostly concern us the law of skin-friction is very little different from that which obtains in other cases of fluid resistance, namely, it varies approximately as the square of the velocity, and is nearly independent of the kinematic viscosity of the fluid, but it conforms less closely to this law than is generally the case. For example, the resistance experienced by a plane in normal presentation expressed as pressure (force per unit area) is given by the following expression:—[11]

$$P_{90} = \mathbf{C} \times \rho V^2$$

in which, when absolute units are employed, the constant **C** has a value lying

[4] Compare Fig. 33, Proc. Inst. Automobile Engineers, Vol. IX, p. 247.
[5] " Aerodynamics," §182, *et seq.*
[6] " Aerodynamics," Fig. 98, p. 212, Fig. 114, p. 266, also Figs. 117A and 117B, p. 277.
[7] " Aerodynamics," §§184, 187.
[8] " Aerodynamics," Chap. II.
[9] " Aerodynamics," §48. Also Proc. Inst. Automobile Engineers, *l.c. ante.*
[10] " Aerodynamics," 1907, §§35, 50.
[11] For meaning of symbols refer Part IV, §33.

ordinarily between 0.55 and 0.62. The variation in this constant is due to the fact that the Reynolds number does not appear in the expression, whereas strictly speaking it should, and so the influence of viscosity has not been taken into account. The justification for this is made clear in the form of a diagram (Fig. 1).

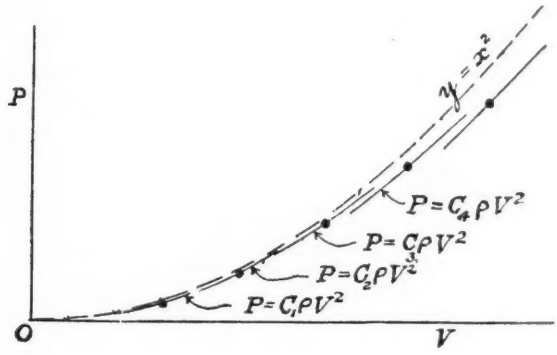

FIG. 1.

Illustrating the approximation to a curve of the form $P = V^n$ *where the index n is near to 2 by graphs in which the index is = 2 corrected from point to point by a variable constant.*

So long as we are dealing with " local " variations in size or velocity the error introduced in assuming the V^2 law is very small, but when the error becomes too great to be neglected a new value of **C** is chosen. The author pointed out when publishing his early work that the kinematic viscosity of air is about fourteen times as great as that of water, fundamentally this was no new discovery, yet it came as a decided shock to those who had learnt to regard air as the more perfect fluid and lightly dismissed the surface drag as negligible.[12] And so it comes about that at ordinary velocities, and for ordinary magnitudes, the value of **C** in the case of water is in the region of 0.55, the lower figure given, and that for air is more nearly = 0.6. This is for the normal plane, of more or less square proportion.

§7. It is generally supposed that in the case of skin-friction the departure from the simple form of expression given above is more marked, but experimental data is conflicting. From the determinations made by William Froude[13] the value of the index, computed by him, is given as varying between 1.83 and 2.06, but it seems improbable that the index can, under any circumstances, be greater than 2, that is to say, it is unlikely that the resistance would increase at a greater rate as a function of speed than V^2. Nothing, however, seems impossible when we are concerned with the dynamics of the real fluid.[14] Many of the leading authorities assign a value of approximately 1.85 to this index as applying to marine conditions,[15] but the author regards this as too low. For the wings of a present-day aeroplane the index is probably in the region of 1.85 to 1.9, and

[12] See Langley, " Experiments in Aerodynamics," pp. 9, 23, 25, 64 and 65 (Fig. 11), Smithsonian Institution, Washington.

[13] Wm. White, Naval Architecture, p. 441; John Murray, London.

[14] Adv. Comm. for Aeronautics, Tech. Report, 1913-14, p. 43. " The Resistance of Spheres." Also 1915-16, R. & M. 190, pp. 19 *et seq.* Compare §9.

[15] Where the Reynolds number commonly exceeds 10^8. In the case of a vessel 100ft. in length at 10 knots, the Reynolds number is 10^8.

for the body somewhat in excess of that figure; for a modern airship of the rigid type, or an ocean-going liner, the index will probably be not less than 1.94.

Whatever the figure may be, we are justified (except for low values of $\mathbf{N}_R$)[16] in assuming the V^2 law to apply, provided that in every case an appropriate choice of constant be made; then if we denote this constant by the symbol $\mathbf{C}_o$ as applying to the resistance or drag of a plane at zero angle, of which the value per unit area is given by P_o,

$$P_o = \mathbf{C}_o \rho V^2$$

Or if we use the symbol R_f to denote the frictional resistance,

$R_f = \mathbf{C}_o \rho V^2 \times 2a$; $2a$ being the area of "wetted" surface, *i.e.*, twice the actual area a of the plane.

§8. We may now turn our attention to the Reynolds number which the author denotes by the symbol $\mathbf{N}_R$, given by the expression[17] LV/ν (absolute units). Assuming the strict applicability of dimensional theory, it is the Reynolds number that in every fluid and under all conditions determines the value of the constant $\mathbf{C}_o$. Usually $\mathbf{C}_o$ is a single valued function of $\mathbf{N}_R$, but there is some doubt as to whether this is invariably the case.

As practised, there are various ways of recording the results of observation concerning skin-friction, whether it be in relation to flat plates or to the direct resistance of ichthyoid bodies, or of spar or aerofoil sections. Some prefer to present their work *reduced* in some manner, others endeavour to fit their observations into the framework of an empirical equation of some kind, and from this equation extrapolate and give results which are outside the range of observation. Others again are content to give their results exactly as determined, either tabulated or plotted, or both. The latter is the course which the author considers preferable. The best form of chart on which to plot such data is one in which abscissæ represent values of the Reynolds number and ordinates values of the constant $\mathbf{C}_o$, both scales being logarithmic (Fig. 2, Plate). On this chart will be found plotted data collected from various sources, a few only of the points spotted relate to the author's own determinations. The plottings are identified by lettered and numbered references.

§9. One point which attracts immediate attention is the almost complete lack of consistency between the results, especially as concerns the ichthyoid forms. And then there is the extraordinary ambiguity in the region of $\mathbf{N}_R = 10^6$ where it would appear that the constant $\mathbf{C}_o$ is no longer a single valued function of the Reynolds number. There seems to be a condition of instability in this region, first observed by Mr. G. Baker,[18] and later by Prof. Jones[19] and signalised on the chart by some extraordinarily low values of $\mathbf{C}_o$ as discovered in a series of determinations made on a model of airship R.101.[20]. These things lead one to feel some doubt whether under all conditions Froude's rule is applicable. There is a great deal still in need of elucidation. So far as the present paper is concerned, the author will content himself with presenting this chart as showing how difficult it is at present to generalise. It will be observed that there is one unbroken line drawn through the conflicting mass of empirical data; this is an attempt to represent an average of that which has been recorded by different observers; a poor attempt admittedly, but one which the author has found may be used as representing a (minimum) skin-friction constant relating to a physically

[16] $\mathbf{N}_R$ is the symbol used by the author for the Reynolds number LV/ν. Compare §8 and Part IV, §33.

[17] For meaning of symbols see §33.

[18] "Notes on Model Experiments." Proc. North-East Coast Inst. Engineering and Shipbuilding, Vol. XXXII, 1915. See also Appendix III.

[19] R. & M. 1199.

[20] R. & M. 1168.

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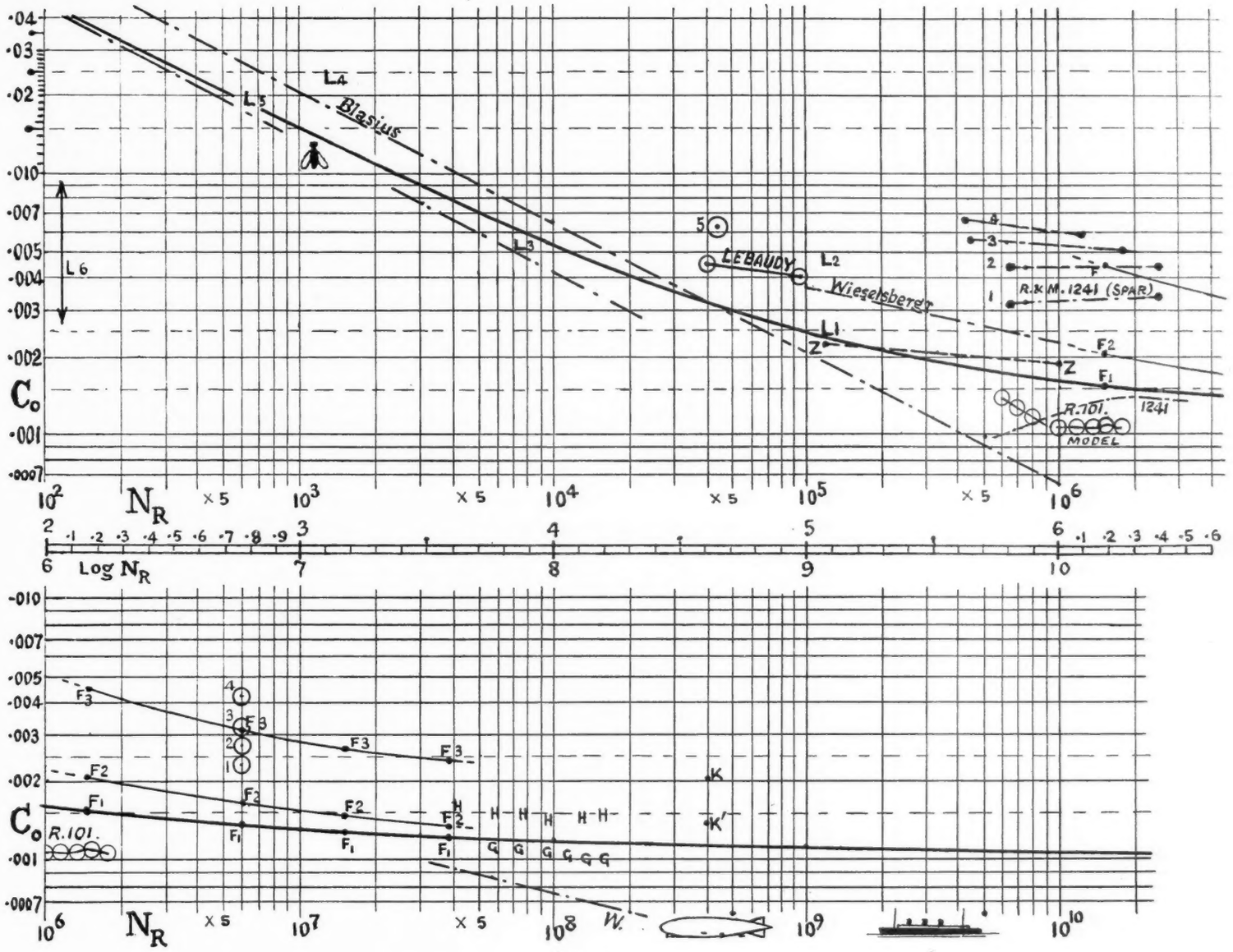

FIG. 2.

Plottings of data relating to skin friction are given in the above chart, logarithmic scales being used. Ordinates represent values of the constant $\mathbf{C}_o$ and abscissæ stand for the Reynolds number $\mathbf{N}_R$. This form of record has been kept by the author for many years, and extended from time to time. A key to the various references is given below. The smooth graph extending from end to end of the chart is an attempt to represent the relation of $\mathbf{C}_o$ to $\mathbf{N}_R$ empirically. The only guide from theory is, that for low values of $\mathbf{N}_R$ the law of laminar flow, *i.e.*, *resistance* $\propto V^{1\cdot5}$ is assumed, approached asymptotically; whereas for high values of $\mathbf{N}_R$ the graph approaches asymptotically to the law of *resistance* $\propto V^2$.

It will be seen that a house fly is depicted appropriately in the region of $\mathbf{N}_R = 1{,}000$. Ranging from 3×10^8 to 7×10^8 the outline of an air ship is exhibited representing the range of values of $\mathbf{N}_R$ covered by the general run of such craft. Similarly, from 2×10^9 to 5×10^9 is shown as covering the range of values of $\mathbf{N}_R$ for ocean-going vessels; this is indicated by a silhouette of the liner "Queen Mary." On the left is given an inclined line corresponding to the equation for laminar flow given by Blasius. This suggests that the empirical graph in this region may be too low. In the region embraced by values of $\mathbf{N}_R$ from 1.5×10^6 to 4×10^7 graphs are given F_1, F_2 and F_3, these represent the determinations of the late William Froude, and refer to planes surfaced with tinfoil, varnish, and calico respectively; F_1 (tinfoil) has been taken in as part of the empirical graph. To the right of this, observations by Gebers* (G, G, G) and by ————† (H, H, H) have been plotted and for a still higher value of $\mathbf{N}_R$ two observations are given, K′ due to Kármán and K for a surface comprising plate butts and rivet heads due to Kempf.‡ Ranging downwards from 10^6 to 10^5 a graph marked Z, Z, refers to a number of determinations by Zahm,§ and higher up on the chart in the region of 10^6 a number of graphs may be seen relating to spar sections (from R. and M. 1241). Lower on the chart determinations relating to a model of the British airship R.101 are plotted (from R. and M. 1168), these and other airship model determinations are indicated by circles. At $\mathbf{N}_R = 6\times10^6$ plottings are given of four airship models of various degrees of fineness ratio (from R. and M. 1911), thus:—

No. 1 fineness ratio 6.5	No. 3 fineness ratio 5.1
,, 2 ,, ,, 6.1	,, 4 ,, ,, 4.1

Observation 5 relates to a model No. 3, R. and M. 17. Fineness ratio 4.7. And two determinations relating to the Lebaudy airship are given at 10^5 and 5×10^4. Running in an almost direct line from Lebaudy to F_2 is a chain line marked "Wieselsberger," plotted in accordance with his equation. This line is picked up again in the region $\mathbf{N}_R = 10^8$ (low down on the chart); it appears to be of little or no value. The positions marked L_1 and L_2 are two determinations made by the author by means of his aerodynamic balance ("Aerodynamics," §246), in L_1 the surface was of burnished gold leaf, in L_2 the test plane was coated with Oakey's No. 2 glass paper. L_3, L_4 and L_5 represent determinations made with small mica planes forming part of model gliders ("Aerodynamics," §§241 *et seq.*). The line marked L_6 on the extreme left of the chart denotes the range of values of $\mathbf{C}_o$ used by the author in calculating the tables presented in his "Aerodynamics" in 1907.

A scale is given of Log. $\mathbf{N}_R$ values, to enable the values of $\mathbf{C}_o$ to be compared directly with those given by the Aeronautical Research Committee, this being the scale usually employed in their reports.

* Schiffban IX Jahr. Plotting uncertain.
† Reference doubtful.
‡ Trans. N.A., Vol. LXXI, p. 104.

§ Phil. Mag., July, 1904, p. 58.

smooth surface with a certain amount of confidence, not, however, without misgivings concerning the region of abnormality to which attention has been called.[21]

§10. The computation of the resistance of airships and airship models, also aeroplane bodies of ichthyoid form, is a very much vexed and exceedingly difficult matter.[22] The author, for large models (more generally when the value of $\mathbf{N}_R$ is high), and where the fineness ratio exceeds the value 5, trusts to the theory as established in naval architecture, and has yet to learn when and at what point Froude's rule breaks down,[23] but certain it is for fineness ratios less than 5, what is gained as a diminution in skin-friction is, in part, lost on account of the increased bluffness. One glance at the chart (Fig. 2) is enough to show how far we are from being able to form any exact conclusions.

This difficulty was not unknown to the author in 1914 when he gave his James Forrest Lecture,[24] and in dealing with the subject then he expressed the resistance of ichthyoid bodies in terms of their normal plane equivalent, giving his authority in each case; even so expressed, there was very little in the way of agreement. Under these conditions the author adopted provisionally a rough and ready rule, in respect of which he is aware that he lays himself open to criticism. It is this: That for all well-formed airship models (true ichthyoid forms) of fineness ratio = 5 and above, Froude's rule shall apply. For bodies whose fineness ratio is lower the resistance shall be founded on an equivalent area of normal plane. This equivalent area may vary as from about 0.03 to 0.02 of the area of maximum section, or the resistance may be calculated by making use of a constant $15 \times \mathbf{C}_o$ on the maximum sectional area.[25]

§11. The Graf Zeppelin airship may be treated as an example of the application of Froude's rule.

Data.

Length = 772 ft.	Fineness ratio 7·7
Diameter = 100 ft.	Sectional area, 7,800 sq. ft. (max.)
Speed (max.) = 117 ft./sec.	$\mathbf{N}_R = 6 \times 10^8$
" Wetted " surface—	
Hull, 175,000 sq. ft.	$\mathbf{C}_o$ (for body)[26] 0.00115
Fins, etc., 6,000 sq. ft.	$\mathbf{C}_o$ (for fins)[26] 0.0013
5 gondolas, 40 sq. ft. sectional area; total 200 sq. ft. taken equivalent to 80 sq. ft. normal plane.	$V^2 = 13{,}700$ R = resistance.

Hull.

$$R = 0.00115 \times 0.078 \times 13{,}700 \times 175{,}000 = 215{,}000 \text{ pdls.} = 6{,}660 \text{ pounds.}$$

Fins, etc.

$$R = 0.0013 \times 0.078 \times 13{,}700 \times 6{,}000 = 8{,}300 \text{ pdls.} = 259 \text{ pounds.}$$

Gondolas.

$$R = 0.6 \times 0.078 \times 13{,}700 \times 80 = 51{,}500 \text{ pdls.} = 1{,}600 \text{ pounds.}$$

Total resistance = 8,519 pounds.

From which, the thrust power $= \dfrac{8{,}519 \times 117}{550} = 1{,}810$ h.p.

[21] §9. Also see Appendix III.
[22] Actual determinations made in the wind tunnel also show glaring inconsistencies.
[23] Except as concerns the ambiguity in the region of $\mathbf{N}_R = 10^6$. See Appendix III.
[24] " The Flying Machine from an Engineering Standpoint," *l.c. ante*, p. 44.
[25] $\mathbf{C}_o$ being chosen appropriate to the Reynolds Number based on L the length of the model. Compare §38.
[26] These are minimum values.

or, with due allowance on account of propulsion loss (efficiency taken = 75 per cent.) 2,410 b.h.p.

This compares with 2,650 declared total h.p. being the output of five engines of 550 h.p. each. It is possible that the estimate given above errs on the side of being too low.[27]

§12. Let us next consider on the same footing the case of the hull or body of an aeroplane on the understanding that it is treated as a true ichthyoid or streamline form. That is the ideal at which every designer aims, and in approaching this ideal, a great advance has been made during the last few years. We will take for our purpose a passenger-carrying machine and assign to the body a maximum diameter of 8 ft. and specify it as a "solid of revolution." We will assume 5 as the fineness ratio, giving the length as 40 ft. The speed will be assumed to be 275 ft. sec. The Reynolds number (based on length) $= 7 \times 10^7$ and the value of C_0 corresponding to this may be taken = 0.0015.[28] The "wetted surface" with a normally formed body will be 750 sq. ft. and the total resistance or drag,

$$= 0.00150 \times 0.078 \times 75{,}500 \times 750 = 6{,}600 \text{ poundals} = 205 \text{ pounds.}$$

The power needed to propel this body through the air at the speed given will be $205 \times 275/550 = 102.5$ h.p., which, with due allowance for propeller efficiency, will mean about 135 shaft h.p. *This must be regarded as the irreducible minimum.* Owing to resistance due to functional organs—excrescences of various kinds—the drag and consequently the h.p. necessary would be actually greater.

The alternative method of computing the body resistance $15 \times 0.0015 \times 0.078 \times 75{,}500 \times 50 = 6{,}600$ poundals = 205 pounds as before. The wind force on a normal plane of the same area, 50 sq. ft. would be,

$$0.6 \times 0.078 \times 75{,}500 \times 50 = 177{,}000 \text{ poundals.}$$

That is to say, the resistance of the body (on either basis) is about 1/27th of that of a normal plane presenting the same area to the wind. This is within 10 per cent. of the figure supplied to the author by M. Surcouf, the well-known French airship designer, in 1908.[29]. It is only one-third of that given by M. Colliex (of Voisin Freres, Paris) that same year whose figure, and many others of the values then reported were far higher.[30]

The fineness ratio in the above example, 5/1, is approximately that at which the author suggests the change in the method of computation should be made, and as exemplified it is the ratio at which the two methods give the same result.

§13. It will be observed that in the foregoing the Reynolds number has been based upon L as being the length in the line of flight. The bare mention of a Reynolds number is without meaning, it is always necessary to specify the linear parameter on which it is based.[31] In the case of skin-friction, experience has shown that the all-important dimension is that corresponding to the direction of motion. If it were necessary, as in other cases, to insist on strict geometrical similarity, then having defined the form to which this condition relates, *any* choice of linear parameter is valid, but where skin-friction is concerned the resistance per unit area is *nearly* independent of the transverse dimension of the test plane, and we are released from the strict observance of the condition of similarity provided that L be chosen as stated: we are not here considering extreme cases.

As already stated, Froude laid it down that the resistance experienced by the hull of a vessel, due to skin-friction, could be computed by considering it as a

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[27] Had we made use of "augmented" values (see Appendix II) the hull resistance alone would have been 8,250 pounds, and the total (shaft) h.p. = 2,800.

[28] Augmented value (compare Table, Appendix II).

[29] M. Surcouf's figure was 1/30.

[30] "The Flying Machine from an Engineering Standpoint," p. 44, Constable, London.

[31] In most of the early Reports and Memoranda of the official Committee the linear parameter chosen has been the cube root of the volume.

plane of length equal to the water line and presenting a total " wetted " surface equal to that of the vessel; this rule may not appeal to the college-trained laboratory worker of to-day, and indeed if the observations plotted in Fig. 2 are to be relied upon there is ground for a little scepticism. Nevertheless Froude's rule has served the purpose of the naval architect and engineer for the greater part of a century, and applied as above to the Graf Zeppelin the method may be deemed to have justified itself.

§14. It has been stated that the variation in the value of $\mathbf{C}_o$ as a function of the Reynolds number is comparatively small and that this entitles us to make use of the equation in which the drag is given as proportional to V^2 and at the same time proportional to the area or to the square of a linear parameter.

A word of warning may, however, be given. For very low Reynolds numbers such as are met with in the case of small-scale models either in free flight or in the wind channel, this is not the case, the lower the Reynolds number the greater the departure in the index value, and ultimately the V^2 law ceases to be a sufficiently close approximation. This will be abundantly clear from an inspection of Fig. 2; towards the left for low values of $\mathbf{N}_R$ the index is approaching that of laminar flow; namely, 1.5.[32]

From now onward, unless otherwise stated, it will be taken that, as concerns skin-friction, the law of resistance varies as V^2 will apply. The author adopted this convention in his " Aerodynamics " some thirty years ago and he has since seen no reason to abandon it.

PART II.

THE ECONOMICS OF FLIGHT.

Aerodynamic Resistance and the Newtonian principle; application of, in its relation to the Vortex Theory. The elementary equations arising from Newtonian dynamics. Difficulties of application. The peripteral area: importance of: and definition. The author's Propositions concerning the economics of flight.

§15. It now becomes necessary to enter into a discussion of general theory as concerns the economics of flight and the resistance due to the act of sustentation. The author formerly termed this the *aerodynamic resistance* and in the present paper he will maintain that designation; whether this is identical with that which in aeronautical circles is known as " induced drag " he cannot say; if it should be so the latter term seems doubtful as an example of terminology in view of the fact that *aerodynamic resistance* is the one species of resistance which is essential to flight. If *aerodynamic resistance*, used throughout in the author's earlier writings, be deemed too long-winded, the author would favour *primary drag*; in this paper he will, however, adhere to his previous practice and use the term *aerodynamic resistance* to denote the drag essential to the act of sustentation.

§16. Before dealing with the author's own theory which in its inception dates from 1893-4 and which will be found set forth at length in his " Aerodynamics " (published in 1907) and further developed in a paper read before the Institution of Automobile Engineers in 1915,[33] a few words will be given on the theory of sustentation based on principles enunciated by Sir Isaac Newton and subsequently developed by Rankine in relation to propulsion.

The Newtonian principle on which sustentation ultimately depends has been otherwise stated as the *doctrine of the continuous communication of momentum.*

[32] Compare Appendix II.

[33] Proc. Institution of Automobile Engineers, Vol. IX, p. 171, *et seq.* See also Journal of the Royal Aeronautical Society, No. 190, Vol. XXX, 1926; (Wilbur Wright Lecture).

It is the same principle as that by which a rocket is sustained in its flight, but whereas in aerial flight it is the mass of air per second to which downward momentum is imparted, and which provides the reaction to which sustentation is due, in the rocket it is part of the substance of the rocket itself which is projected downward. Rightly considered the practical purpose of the author's vortex theory is to *enable the mass of air dealt with per second to be evaluated*, once that is achieved the Newtonian principle may be applied in a manner analogous to that adopted by Rankine and Froude when investigating the problem of marine propulsion.

It is fundamental that if a mass be set in motion by an applied force, the momentum communicated in one second (or per second) is the measure of that force. Thus using absolute units in any system, let m/s = mass per second and v the velocity imparted. Then

$$\text{Force} = (m/s)\, v \quad . \quad . \quad . \quad . \quad . \quad (1)^{34}$$

Then if W represent the weight sustained, *i.e.*, the force of gravity acting on a body sustained in flight, and if m/s = mass of air acted upon uniformly per second, and impelled downward with velocity v then the above equation applies, and in absolute units work done per second,

$$= (m/s)\, v^2/2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Therefore, if V be the velocity of flight the resistance (aerodynamic resistance), due to sustentation

$$= (m/s)\, v^2/(2\,V) \text{ or drag/lift} = (m/s)\, v^2/(2\,VW) \quad . \quad . \quad (3)$$

§17. Now it is necessary to make a confession: *in the actual problem of flight these equations cannot be directly applied*. In the first place there is no *a priori* basis on which to assess either m/s or v; in the second place, since the atmosphere as a whole does not receive a downward velocity, there must somewhere be an upward velocity imparted, and the upward displacement must be precisely equal to the downward displacement. These difficulties are discussed very fully in the author's "Aerodynamics,"[35] where it is pointed out that the weight W is eventually borne by the earth's sub-jacent surface. Newton himself made no attempt to solve this problem, he contented himself with inventing a "medium," discontinuous in its nature, and enunciated certain propositions concerning that medium; it is in this connection that he deduced the law that for an inclined plane at an angle β to the line of motion the pressure reaction varies as $\sin^2 \beta$, that is the *square of the sine* of the angle.[36] Under similar conditions it has long been known that, to air and to other fluids possessed of continuity, this law does not apply; it is more exact to say that the magnitude of the reaction, is *directly proportional* to the sine of the angle itself.[37] Yet it is necessary here to be careful, because although the direct sine law applies with considerable exactitude to planes of high aspect ratio or even those of square form or proportion (aspect ratio = 1) for values less than unity, namely, for long narrow planes in endwise presentation the law gradually changes, till in the limiting case, which we may visualise as that of the broom-handle on which, it is alleged, in past times, witches were wont to perform their nocturnal flights, the law of the Newtonian medium applies.[38]

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[34] Dimensionally,

$$\mathbf{ML/T^2} \equiv (\mathbf{M/T}) \times (\mathbf{L/T}).$$

[35] §§5 *et seq.* Also §112.

[36] Some writers have misrepresented Newton as having put forward this "law" as applying to air. Langley, for example, "Experiments in Aerodynamics," p. 24; p. 89 line 2; p. 105 last 3 lines. Compare author's "Aerodynamics," §238, p. 366.

[37] First enunciated by Vince, Phil. Trans. 1798.

[38] Compare "Aerodynamics," §§149 *et seq.* It is well here to call attention to the difference between the theory of the *Newtonian medium* and the *Newtonian* principle as applied by Rankine and by the present writer.

§18. Taking our stand on the law $W \propto V^2 \sin \beta$, as having been established by experiment, it is legitimate to assume that the angle β comes within the definition of a *small angle*, which is that the angle (in circular measure) and sine (or tangent) are sensibly equal to one another.[39] Then the downward velocity $v = V \sin \beta$. Let A' be the area of a horizontal column or stratum of air representing the mass to which a downward velocity v is imparted; then

$$W = V^2 \sin \beta \times \text{const. and } v = V \sin \beta$$
$$W = (m/s)\, v = A\rho V v = A'\rho V^2 \sin \beta$$

Hence,

$$A'\rho V^2 \sin \beta = V^2 \sin \beta \times \text{const.} \quad . \quad . \quad . \quad . \quad (4)$$

or

$$A' = \text{const.}/\rho = \text{constant.} \quad . \quad . \quad . \quad . \quad (5)$$

The conditions may be represented by considering the plane or aerofoil as acting uniformly on a horizontal layer of air of constant cross section; this is referred to in the author's work as the "sweep" of an aerofoil (Fig. 3). Assuming

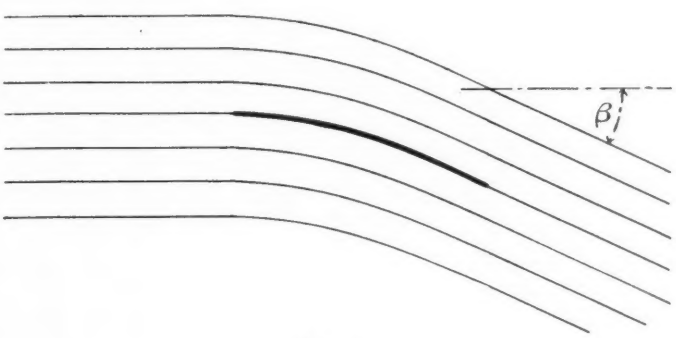

FIG. 3.

Conventional diagram illustrating stream as deflected without taking vortex system into account.

constant "sweep," and denoting this area by the symbol A' the mass of air handled per second is $A'\rho V$ and the velocity v as before $= V \sin \beta$, then $W = A'\rho V^2 \sin \beta$.

For a considerable range of values of β this equation is in qualitative agreement with experiment, but the quantitative interpretation is lacking, the magnitude of A' is unknown.[40] Furthermore, as pointed out A' has no literal existence, the motion imparted to the air is as much upward as downward and there are horizontal counter currents in addition, also the velocity cannot be rightly expressed by a single value of v. All this is enough to raise doubts as to the applicability of the Newtonian method, and in the early days the author was much exercised in his mind as to whether this line of thought could be followed up with profit. Still Rankine had blazed the path in connection with propulsion, it seemed almost certain that the difficulties could be overcome.

§19. The experiments of Langley and others with pairs of superposed planes seemed to indicate that the thickness of the effective stratum of air was in the region of the fore-and-aft dimension of the planes, this would give a sweep area A' *approximately*[41] $= a$ where a = the area of the plane or aerofoil. But this

[39] Actually the law holds for angles considerably greater than included in this definition.
[40] So far as the present discussion has carried us.
[41] A'/a varies as a function of the aspect ratio.

was found to result in values of W far below those experimentally determined. It was at this juncture (about 1893) that the author first formulated his vortex theory, which pointed to the fact that the air within the sweep was received by

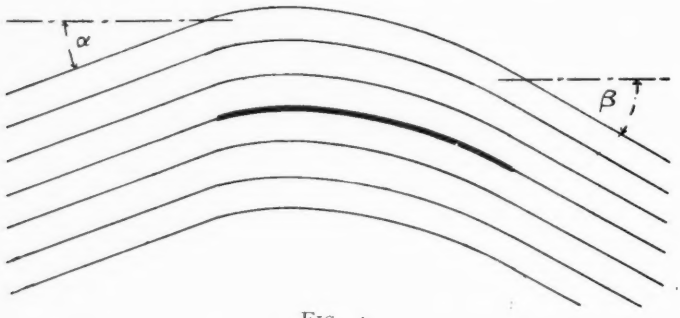

FIG. 4.

Conventional diagram illustrating stream as deflected taking account of the vortex system.

the plane or aerofoil in a state of upward motion[42] (Fig. 4), so if v_1 be the (upward) velocity and v_2 be that of downward discharge in the application of equation (1),

$$v = v_1 + v_2, \quad W = (m/s)(v_1 + v_2) \quad . \quad . \quad . \quad . \quad (6)$$

and the energy expended per sec. $= (m/s)(v_2^2 - v_1^2)/2 \quad . \quad . \quad (7)$

By the aid of methods in which mathematical reasoning played a subsidiary part, the theory, as developed, was shown to lead to results in harmony with experience, but the author had not at his disposal apparatus such as would have enabled him to put it to any crucial tests; his resources were limited and his experimental work consisted mainly in observations conducted by the aid of small model gliders in free flight. That these did not give results in entire agreement with theory was to be expected,[43] the Reynolds number was below 100,000 and $\mathbf{C}_0$ the skin-friction constant was never less than 0.0025.[44] The author was aware of the disabilities under which he laboured; he published his theoretical generalisations, but allowed himself to be very conservative in their application.

§20. Founded on the expression for energy expenditure (7), the author was led to entertain the conception of a *peripteral area*, which would define the mass of air coming within the effective grasp of an aerofoil, and allow of the direct application of the Newtonian principle, this area to take the place of the sweep in all calculations, and in relation to which, weight sustained W, the mass per second m/s, and the velocity of downward discharge v, would stand as related in equation (1), and energy as in equation (2). The expression for this area is given in "Aerodynamics," §§210,[45] 211, p. 309.

$$\{(1+\epsilon)/(1-\epsilon)\}\ \kappa a$$

[42] "Aerodynamics," §§112 *et seq.*

[43] Compare Part V.

[44] See footnote, §33.

[45] The definition is given in the concluding paragraph of §210. "Now, we may evidently regard the aerofoil, with its accompanying peripteral system, as the *equivalent of the hypothetical device which we have temporarily assumed.* The peripteral system actually constitutes a kind of tool or appliance by which the aerofoil is able to deal in effect with more air than actually comes within its sweep. This extended 'sphere of influence' of the aerofoil will be termed the *peripteral zone*, and its cross-section, $\{(1+\epsilon)/(1-\epsilon)\}\kappa a$ is the *peripteral area.*"

the meaning of the symbols being given pp. 245, 249 (§§171, 173) and computed values of ϵ and κ as related to aspect ratio, p. 261, §181. Also p. 312, Table XIII.[46]

§21. On the assumption of "constant sweep" it has been made clear that *aerodynamic resistance* varies inversely as the square of the flight velocity. The author believes this was already established before he himself entered the field, and before Langley, but in any case it was clearly stated by Langley[47] though he, unfortunately, believed this to be the only form of resistance necessary to flight, and in his publication presented a far too rosy and optimistic picture of the future of heavier-than-air aeronautics, in which the faster you fly the less power required![48]

The mere recognition of the fact that there are two species of resistance whose sum represents the total drag, the one varying directly as the square of the velocity[49] and the other inversely as the square, even without the means of evaluating either leads to some conclusions of importance.

On this basis it is shown as in the author's "Aerodynamics," §164, that *the total resistance is least when the direct resistance and the aerodynamic resistance are equal to one another.*[50] It is further shown that *the velocity of least power expenditure (the longest time in the air on a given supply of energy) is that at which the aerodynamic resistance is three times the direct resistance.*[51] And further, that *the speed of greatest range (i.e., least resistance) is* 1.315 *times the speed of least power.*[52] These are important results, and the only qualification it is necessary to make (beyond the basic assumption of constant sweep) is that the wing section is appropriate to the speed of flight, a condition which from a practical standpoint is capable of being realised. A diagram (Fig. 5) is given showing the implication of this theory in more general terms, being Fig. 112 from the author's work cited.[53]

§22. When *variations of design* are involved, the direct resistance of the body, and the direct (skin-frictional) resistance of the wings or aerofoil, both varying as V^2 must be considered separately, the assumption is that the weight of the machine is definitely settled, and the body has been designed for some particular service and cannot be varied; then the wings alone are subject to variations in design to conform to the flight speed specified, whatever that may be. It is thus shown[54] that for a machine of given weight designed to travel at a stated velocity, whatever the body resistance may be, the correct design of aerofoil is that in which the aerodynamic resistance is equal to the direct resistance of the aerofoil alone. This conclusion might seem inconsistent with Prop. II, since such a machine would fly with least resistance when the *total* resistance is equal to the aerodynamic resistance; this would be a slower speed than that for which the wing area was designed. The explanation of this apparent paradox is not far to seek.[55] The next case to consider is that of a glider in which velocity and sail area are both variable.[56] Here it is shown that if body resistance be excluded the *total resistance (or drag) under optimum conditions of design is independent of the velocity.* This means that, in considering the possibility of performance, the least total resistance is made up of a *constant* so far as concerns the flight organs, plus a resistance which varies directly as V^2 due to the body,

[46] Compare §28 herein.
[47] "Experiments in Aerodynamics," 1891 (Smithsonian Institution).
[48] "Experiments in Aerodynamics," see ref. §6, footnote.
[49] It has already been demonstrated that all direct resistance, including both skin-friction and that due to errors of form, may for practical purposes be included as varying directly as V^2.
[50] "Aerodynamics," Prop. I, §164.
[51] "Aerodynamics," Prop. II, §164.
[52] "Aerodynamics," Prop. III, §164.
[53] "Aerodynamics," p. 254.
[54] "Aerodynamics," Prop. IV, §165.
[55] Compare Appendix IV.
[56] "Aerodynamics," Prop. V, §166.

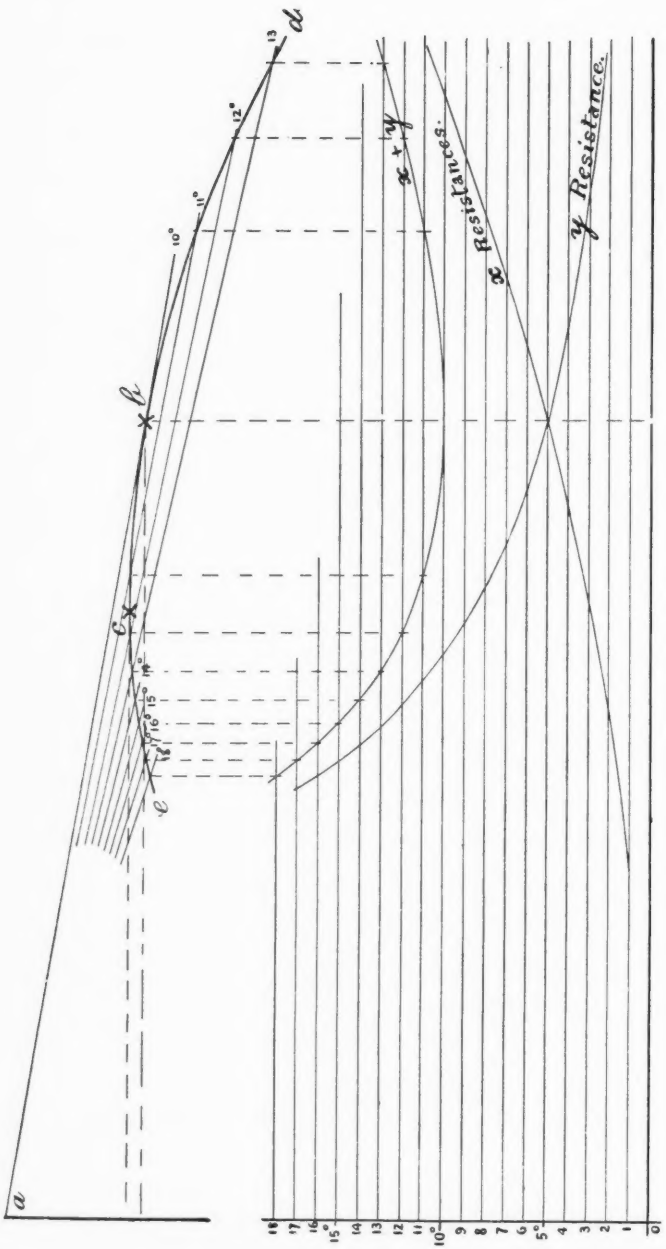

Fig. 5.

Fig. 112 from the author's "Aerodynamics" illustrating the condition of least resistance and slowest descent (least h.p.) and more generally the relation of gliding angle to velocity

depending upon the body size and form. This addition of body resistance results in high speeds being less economical than low speeds and this is inevitably the case. The conditions are strictly comparable to those of a car climbing a steady gradient, the gradient resistance is constant but the windage increases as the square of the velocity.

§23. In order to avoid misunderstanding, it may be stated here, as will later be demonstrated, that this minimum *gradient* depends both upon the *aspect ratio* and upon the *size* of the machine,[57] if these two are pre-fixed then however great the skill of the designer there is a definite minimum gradient beyond which he cannot go, and which, under optimum conditions, for given W, is constant in relation to speed. " Size " of machine must be interpreted as *weight*, otherwise size would involve the Reynolds number. For a given weight, under the condition of best design (assuming aspect ratio constant) the Reynolds number undergoes no change.[58]

The case may be presented briefly thus. In a series of otherwise similar machines of given weight in which, in order to comply with the condition of least resistance, the wing area is varied as a function of the normal flight velocity, it may be shown that a linear parameter of the wing spread, such as the span or the chord, must be made to vary inversely as the velocity. Thus LV (and it follows the Reynolds number) for a given weight sustained is constant; the aspect ratio plays a vital part in determining the value of this constant. This discussion will be resumed when the ground has been more fully prepared (see Appendix II).

Part III.

The Vortex Theory of Sustentation.

Historical sketch, with references. Earlier and later methods of treatment; agreement demonstrated. Distribution of aerofoil load-grading discussed.

§24. We must now return to consider further the author's cyclic or vortex theory of sustentation. It has been pointed out that, until the author introduced this theory, there was no known basis on which to compute or calculate the effective mass of air dealt with by an aerofoil, or the wing spread of an aeroplane or glider in flight. The Newtonian principle was established postulating equality between momentum communicated per unit time and the resultant force; this, coupled with the hypothesis of " constant sweep," gave results which were qualitatively correct, but at first the quantitative data were lacking.[59] Yet, as pointed out, the method had yielded good results in the problem of propulsion in the hands of Rankine and Froude, in which similar difficulties arise. Although the material necessary and quantitative data were given and tabulated by the author in his earlier work, it was not till 1915 that he was able to confirm this by supplying a solution founded on a more precise conception. An account of this will be found in a paper communicated to the Institution of Automobile Engineers in 1915, and in a paper contributed to the International Engineering Congress, in San Francisco, of that same year. Also a résumé was given in the author's Wilbur Wright Lecture in 1926.[60] The present is not the occasion to recapitulate the whole story—a general familiarity with the cyclic theory on the part of those to whom this paper is addressed will be assumed. However, there are certain less familiar aspects of the subject to which, for the sake of the

[57] A high aspect ratio is beneficial because it results in a diminished direct wing resistance. The larger size gives relief on account of the *scale effect*, i.e., a lower Reynolds number, and as a consequence a somewhat lower value of $\mathbf{C}_0$.

[58] See Appendix II. Also " The Flying Machine from an Engineering Standpoint," p. 94; Constable, London.

[59] The difficulties arising in the application of the Newtonian principle have already been pointed out and references made to the discussion in §§5 to 10 of the author's " Aerodynamics " (*l.c. ante*).

[60] Published in the Journal of the Royal Aeronautical Society, October, 1926.

context, it is necessary to give prominence. The first point of interest is that according to classic " hydrodynamics " a sustaining reaction is derived as a result, almost an unexpected result, of a system of flow proper to a doubly connected region, and as such it appears as a consequence in considering the motion of a perfect (*i.e.*, inviscid) fluid in a state of circulation,[61] defined as irrotational. As originated by the author the converse method of attack was adopted, the reaction on a plane or other form of aerofoil is taken as the basis and the type of flow deduced therefrom. The author's original line of approach,[62] although not leading at once to quantitative results, or enabling the streamlines to be plotted, had certain advantages, it brought into prominence the physical realities of the theory, and, as will now be shown, provided one definite fact which has been turned to account.

§25. In its initial form the author's theory was based on the conception of an aerofoil of some kind, in the first place deemed to be of infinite lateral extent or, alternatively, supposed to have its lateral extremities masked by two parallel vertical walls. Under these conditions a single vertical section such as may be displayed in the form of a diagram, is representative of the whole field, in other words, the flow is two-dimensional. This was shown to give rise to a completely conservative system in which once the system was inaugurated no continued expenditure of energy was needed to sustain flight. A complete confirmation of this was found in the classic so-called hydrodynamic theory,[63] but whereas the author was (on his initial hypothesis) only able to deal rigidly with a plane in edgewise presentation, the more powerful mathematical weapon showed that the result would hold good for any form of core; although only certain special cases could be solved and plotted, the motion could be analysed as a circulation around the core, with a superposed rectilinear motion. But in turn the mathematical theory had to acknowledge defeat because in practice in a real fluid, only certain forms of core are available, namely, those which do not give rise to discontinuity in the system of flow. All these things are now well understood.

The point that it is necessary to stress here is that the horizontal components of the motion of the air in the line of flight, ultimately cancel out. This is made clear with reference to Fig. 6 of the author's " Aerodynamics." Although this

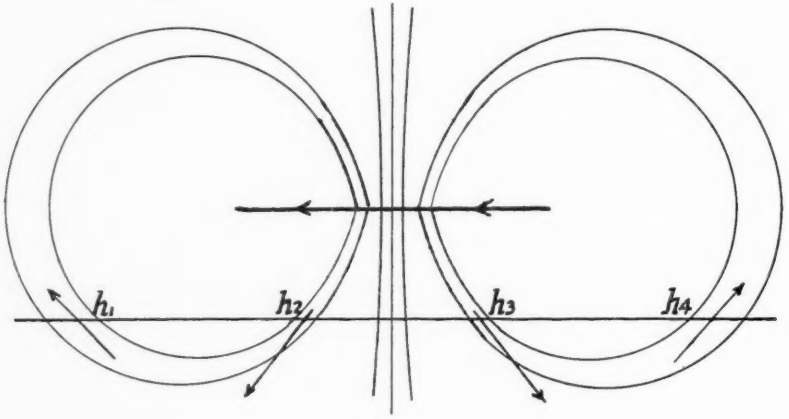

FIG. 6.

Diagram used to justify the ignoring of the horizontal component of air movement in the direction of flight as bearing the vortex theory.

[61] With a superposed motion of translation.
[62] As disclosed in a paper read in Birmingham in 1894. See " Aerodynamics," §§133 *et seq.*
[63] " Aerodynamics," Chapters III and IV.

figure and the argument set forth relate more particularly to the plane or foil of infinite lateral extent, both apply equally to the finite aerofoil at least as a first approximation. When the air has passed out of the field of acceleration the energy left behind in the horizontal component of the residual velocity is negligible. So far as the expenditure of power is concerned the net result would be the same if the particles of air had been so constrained as to be incapable of motion other than in vertical planes at right angles to the direction of flight. The obvious objection to this conclusion is that without residuary velocity in the direction of flight there would (on the Newtonian principle) be no drag. But this objection is easily answered as will appear in due course.[64]

§26. This conception of the problem was first put forward by the author in his paper communicated to the Institution of Automobile Engineers in 1915, to which reference has already been made. It is a purely artificial conception in which the air is supposed to be confined and restricted in its movement by a number of parallel vertical planes, which however are deemed to offer no impediment to the motion of the aerofoil in flight. Within each " cell " formed by adjacent planes (which may be imagined as closely spaced as we wish) the system of flow will be two-dimensional, and as the aerofoil cuts each cell in turn it is deemed to act on the air within, as by an impulse, this being a convention used in hydrodynamic theory. There is usually a little difficulty concerning the application of such an impulse, because it is necessary to postulate that the implement by which the impulse is delivered must be considered as dissolving or vanishing after it has done its work. In the present case this difficulty does not arise because the aerofoil, when its action on any particular vertical stratum is over, is no longer present to obstruct the motion it has set up.

For some time after conceiving this method of treatment the author was casting about for the solution to the resultant system, to give expression to the work done when a plane in a two-dimensional field is acted on by an impulse, it was only when actually preparing the ms. of the paper that he discovered that he himself had already given the solution.[65] The plane is treated as a limiting case of an elliptic cylinder and the system of flow engendered by its motion (Fig. 7) is equivalent to a cylindrical body of air of circular section whose diameter is equal to the span of the aerofoil *acted on uniformly*; that is to say, a mass to which a uniform velocity is imparted. This then is the looked for *peripteral area*[66] of an aerofoil, the area of a circle of diameter = span, and so the Newtonian principle becomes immediately applicable.

§27. Before going further the objection to which attention has been called may as well be dealt with. If the system described were *exactly* as stated, there could be no drag, that is if all movement were confined to motion in a vertical plane. If, however, we conceive the whole system to be tilted out of the " plumb " so that the dividing planes slope upward and backward at a slight angle, roughly in the region of 1 in 40, to 1 in 60, according to the conditions, the air set in motion will have a forward velocity component and the reaction will have a backward component,[67] there will be a *drag*, that is to say, motion will be resisted and the aerofoil will need to be propelled by some agency; we are here only concerned with aerodynamic resistance which, it has been shown, is normally equivalent to half of the minimum gliding angle.

As an indication of the small importance of this correction, on the basis given the expenditure of energy due to the forward component of velocity communicated to the fluid will be only about $(1/50)^2 = 1/2{,}500$ of the total work done.

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[64] §27.

[65] " Aerodynamics," §83, p. 110, concluding paragraph.

[66] See Part II, §21.

[67] If the case be that of gliding flight the imaginary planes may be vertical when the vortex reaction will be in direct opposition to gravity. A component of gravity then supplies the propulsive force. The objection is thus shown to be frivolous.

§28. The result is given above that peripteral area A is equal to the area of a circle whose diameter = span. If S = span,

$$A = (\pi/4)\, S^2 = 0.785\, S^2.$$

For comparison it is of interest to present the results derived from the expression $\{(1+\epsilon)/(1-\epsilon)\}/\kappa a$ already quoted (§20) from the author's "Aerodynamics," this comparison is of especial interest in view of the widely different methods of approach and treatment. The values of **n** given in Table I, col. 1 (from 5 to 10), cover the range of aspect ratio most used.

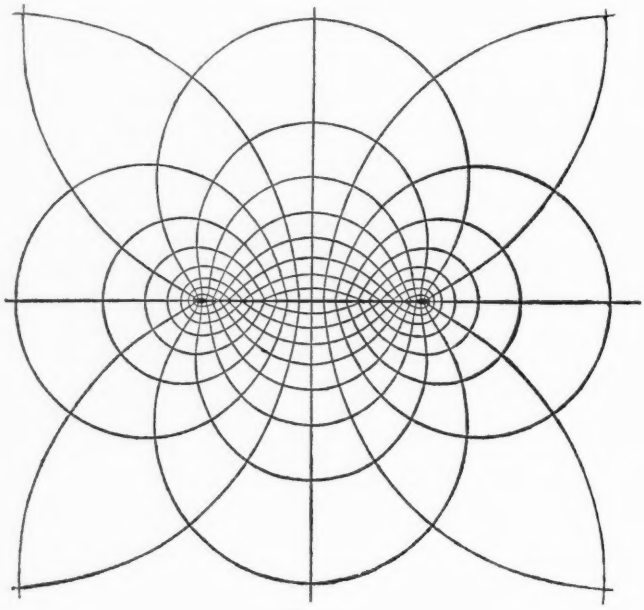

FIG. 7.

The streamline system of a plane under a normally applied impulse, considered as an extreme case of an elliptic cylinder (plotted from the equation).

TABLE I.[68]

1	2	3	4	5	6
n	ϵ	$(1+\epsilon)/(1-\epsilon)$	κ	$\{(1+\epsilon)/(1-\epsilon)\}\kappa a$	$\times S^2/\mathbf{n}$ = peripteral area
5	0.59	3.88×1.064	=	$4.15\ a$	$0.83\ S^2$
6	0.62	4.26×1.10	=	$4.68\ a$	$0.78\ S^2$
7	0.65	4.72×1.12	=	$5.30\ a$	$0.76\ S^2$
8	0.68	5.25×1.14	=	$6.00\ a$	$0.75\ S^2$
..					
10	0.72	6.15×1.175	=	$7.20\ a$	$0.72\ S^2$

Column 5 in the table gives the peripteral area in terms of the aerofoil area. This in terms of S^2 must be divided by the aspect ratio[69] **n** the quotient being

[68] The values of ϵ and κ are as given in "Aerodynamics," §181. A similar Table is given in "Aerodynamics," p. 312.

[69] The elliptical plan-form of aerofoil is here assumed, as adopted by the author as a standard.

given in column 6. According to the author's later theory, as stated above, the peripteral area = 0.785 S^2 for all values of aspect ratio. The agreement is remarkably good.

§29. It will now be clear that when we deal with the peripteral area, A, we make use of the equations (1) and (2) for the calculation of the supporting reaction and for the expenditure of energy respectively, whereas when we make use of the *sweep* of the aerofoil (as in the form in which the theory was first presented), it is equations (6) and (7) which apply.

A few words of warning may be given. According to the author's theory the evaluation of the peripteral area is = $(\pi/4)\ S^2$ that is the area of a circle whose diameter = span; the condition is that of least power expenditure for the weight sustained. This depends physically upon the distribution of pressure reaction along the length of the span being that required by theory, namely, graded in proportion to the ordinates of a semi-circle. Another way of expressing this is, say, that if the plan form of the aerofoil is an ellipse, correct load distribution is such as would be realised if the lifting force per unit area were everywhere the same. It is of interest to observe that the aerofoils used by the author in his early experiments were all of elliptical form, nevertheless his views at that time were not altogether sound on the subject of load grading, he had leanings towards a parabolic load distribution.

§30. The load grading depends to some extent upon the form of the aerofoil, and in assuming the best possible load grading we are presuming that either the best form, or something very near it, has been reached, *or* that our deductions are to be used as a gauge or a criterion of the achievement of the designer. But no other assumption will yield results, for were the grading to be other than that theory demands, then, even if known, it does not give the correct peripteral area, and the Newtonian principle cannot be applied. An example which well illustrates this is to assume a grading uniform along the length of the foil, then hydrodynamic theory tells us that the vortex system set up will be a single vortex pair; in theory this requires an indefinitely great amount of energy for its generation, denoting that such a form of grading could not be achieved even were the attempt made. On the Newtonian principle this would make the peripteral area vanishingly small, instead of, as might be thought, of area = S^2. So far as concerns the works of nature we may rest assured that the process of trial and error implied by the rigorous operation of natural selection will have resulted in a close approximation to the best possible. That the designer of aircraft has reached an almost equal degree of perfection will be established in Part IV of the present paper which follows. As the aerofoil has come to resemble in its general form more and more nearly nature's most highly developed models[70] as exemplified in the wing-spread of the larger soaring birds, so have flying characteristics improved. It has been a mystery to the writer why the early pioneers so often disregarded the teaching of nature in this respect, or, when they did appeal to nature as their guide, they seemed more often than not to have been obsessed by the idea of flapping wings as the essential.

[70] Yet it is surprising how little is the difference between the crude rectangular plan-form of uniform section and the more modern tapered wing with terminal "wash-out"; it would seem that once the general principles are mastered, or appreciated, it is by no means easy to design, unless by deliberate intention, a really ineffective form of aerofoil.

Part IV.

Application: At High Reynolds Numbers.

Comparison of theory and practice. Examples from determinations made in the compressed air tunnel at the N.P.L. Schedule of symbols used. The necessary equations. Examples taken and data, R.A.F. 48, Clark Y.H. and Göttingen 387. Tabulated comparisons and graphic representation. Efficiency as a criterion. Limit of performance: an estimate.

§31. In applying the author's theory to actual examples, as in making comparison with test records, it is necessary to make a distinction between high and low Reynolds numbers. There is no definite line of demarcation but the term "high," as applied to the Reynolds number in this connection, may (as here used) be taken to signify not less than 2×10^6.[71] Where such values apply the agreement between theory and experiment is remarkably good, but when the Reynolds number is below 10^5 there is usually some discrepancy, and in model work the "scale effect" is considerable. For extreme low values the extent of the disagreement may be such that theory no longer serves.

§32. In the first instance the application of the theory will be demonstrated by comparison with experimental data obtained (for high Reynolds numbers) in the compressed air tunnel at the National Physical Laboratory, the results of which have been published in R. and M. 1627. In the data as published it is stated that all necessary corrections have been made, and the author accepts the Reynolds number as given for each series of determinations.[72] The effect of using compressed air is to raise the Reynolds number by lowering the kinematic viscosity. It is established that *viscosity* is almost constant in relation to pressure, therefore the expression for kinematic viscosity, ν being μ/ρ, ν undergoes a reduction in proportion as the density ρ is raised. From the data given it would seem that the temperature within the pressure tunnel is something considerably above normal and not always the same, at least this is the deduction drawn from a comparison made between the corrected values given in the Report, and the corresponding pressures. It would have been more satisfactory if the Report, in addition to giving the corrected values had included the temperatures and other data *as observed*.

While on this subject the author would point out that the Reynolds number is reliable only up to such point as compressibility becomes a factor, that is to say, until the velocity of flight becomes comparable to that of sound. Thus the model of an airscrew, which in "real life" might be cutting wind at the blade tips at a speed of 1,000 ft. a second, might in the compressed air channel, only be cutting wind at 100 ft. a second, and yet have the same Reynolds number. In connection with projectiles the influence of the elasticity of the air is not appreciably felt until the velocity exceeds 70 per cent. of sound or, say, 800 ft./sec. It is unnecessary here to dwell further on this point, it is not likely to be neglected by those responsible for interpreting the results of observation.

§33. In the simple algebraic analysis which will now be given, the symbols used[73] are defined as follows:—

$\mathbf{n}$ is the aspect ratio, defined as the span in terms of the chord, measured on centre line.

S is the span, measured in ft. or cm. according to system used (British or c.g.s.).

A is the peripteral area $= \pi S^2/4 = 0.785\ S^2$.

a is the aerofoil area; for elliptic plan form $= A/\mathbf{n}$. For rectangular plan form $= 1.27\ A/\mathbf{n}$, and for other forms accordingly.

W = weight sustained (abs. units, poundals or dynes).

R = total resistance (abs. units) (R/W = drag/lift).

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[71] In other words greater than the critical value, at which according to report instability is to be feared. For most purposes it is sufficient to make the distinction as above and below 10^6.

[72] The author has found some difficulty in agreeing the figures. See Appendix I.

[73] As far as possible well recognised symbols or descriptive symbols have been adopted.

R_d = aerodynamic resistance (varies as $1/V^2$)
R_f = skin frictional resistance (varies as V^2) } $R_d + R_f = R$.
V = velocity of flight (ft./sec. or cm./sec.).
$\mathbf{C}_o$ = constant[74] in expression for $R_f = \mathbf{C}_o \rho V^2 \times 2\ a$.
N_R is the Reynolds number.
ρ = density.
μ = viscosity.
ν = kinematic viscosity.
K_L is the pressure constant relating to the weight sustained. K_L opt. is value for least K_D/K_L.
K_D is the drag constant.
P = pressure due to weight on aerofoil = $K\rho V^2$ (pressure force per unit area).
m/s = mass of air dealt with per second in accordance with Newtonian dynamics = $AV\rho$.
v = velocity of downward discharge, $W = (m/s)\ v$.

Then the fundamental equations are

$$W = (m/s)\ v = AV\rho v \text{ or } v = W/AV\rho \quad . \quad . \quad . \quad (1)$$

$$W = K_L \rho V^2 a \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\text{Energy per sec.} = (m/s)\ v^2/2 \text{ or } R_d = (m/s)\ v^2/2\ V \quad . \quad . \quad (3)$$

$$\text{But } m/s = W/v \text{ hence } R_d = Wv/2\ V \quad . \quad . \quad . \quad (4)$$

$$\text{or, by (2), } R_d = K_L \rho V a v/2 \quad . \quad . \quad . \quad . \quad (5)$$

$$\text{Hence by (1) } R_d/W = K_L \rho V a v/2\ AV\rho v = K_L\ (a/2\ A) \quad . \quad . \quad (6)$$

$$R_f = 2\ \mathbf{C}_o \rho V^2 a \text{ or, by (2), } R_f/W = 2\ \mathbf{C}_o \rho V^2 a/K_L \rho V^2 a = 2\ \mathbf{C}_o/K_L \quad (7)$$

$$\text{Hence, } R/W = K_L\ (a/2\ A) + 2\ \mathbf{C}_o/K_L \quad . \quad . \quad (8)$$

$$\text{or } K_D = K_L^2\ (a/2\ A) + 2\ \mathbf{C}_o \quad . \quad . \quad . \quad . \quad (9)$$

According to the author's Prop. I the value of K proper to least total resistance or drag, is defined by the two terms R_d and R_f being equal, thus—

$$K_L\ (a/2\ A) = 2\ \mathbf{C}_o/K_L \text{ or } K_L^2 = 2\ \mathbf{C}_o\ (2\ A/a) \text{ or } K_L = 2\sqrt{\{\mathbf{C}_o\ (A/a)\}} \quad (10)$$

§34. The aerofoils as reported in R. and M. 1627[75] were rectangular in plan-form, the span being 4 ft. and the chord 0.666 ft., giving aspect ratio $\mathbf{n} = 6$. For comparison with theory three of the aerofoils tested have been chosen at random, namely, R.A.F. 48, Clark Y. H., and "Göttingen" 387 (Fig. 8).

Using the expression given above $a/2A = 1.27/12 = 0.106$. The value of $\mathbf{C}_o$ depends upon the Reynolds number, the values of which are given. $\mathbf{C}_o$ as taken from the chart (Fig. 2) is as follows:—

"R.A.F. 48"	p. 14, Table 1* ...	$\mathbf{N}_R = 3.56 \times 10^6$.
		$\mathbf{C}_o = 0.0015$.
,,	,, p. 15, Table 2* ...	$\mathbf{N}_R = 6.72 \times 10^6$.
		$\mathbf{C}_o = 0.0014$.
"Clark Y.H."	p. 22, Table 1 ...	$\mathbf{N}_R = 4.43$.
,,	,, p. 22, Table 2 ...	$\mathbf{N}_R = 5.59$.
		$\mathbf{C}_o = 0.00145$ for both.
"Göttingen" 387	p. 26, Table 2 ...	$\mathbf{N}_R = 4.37 \times 10^6$.
		$\mathbf{C}_o = 0.00145$.

[74] In some of his earlier writings the author used a "double surface coefficient" of skin-friction designated by the symbol ξ which betokened the resistance of a flat plate in edgewise presentation in terms of the same plate normal to the wind. Thus,

$$0.6\ \xi = 2\mathbf{C}_o \text{ or } \mathbf{C}_o = 0.3\ \xi.$$

At low values of N_R the values of ξ tabulated by the author in his "Aerodynamics" ranged from .01 to .03, corresponding respectively to $\mathbf{C}_o$ .003 and .009. (See chart, Fig. 2).

[75] Numbers of Tables as referring to R. and M. 1627 *relate to position on page* and are given in ordinary numerals. Numerical references to Tables in text are given in Roman numerals.

* Tables 1 and 2 denote the upper and lower tables in the Report.

In the comparison exhibited in §35, Tables II, III and IV, the calculation has been based on the identical values of K_L given in the report, and the corresponding calculated and observed values of K_D in cols. 4 and 5 are brought into direct comparison; the ratio of the two is given as representing the *efficiency*, the figure for which appears in col. 6. The efficiency thus given is the value of K_D possible according to theory in terms of the K_D as recorded. The assumption is that theory gives a value of K_D which would denote perfect performance.

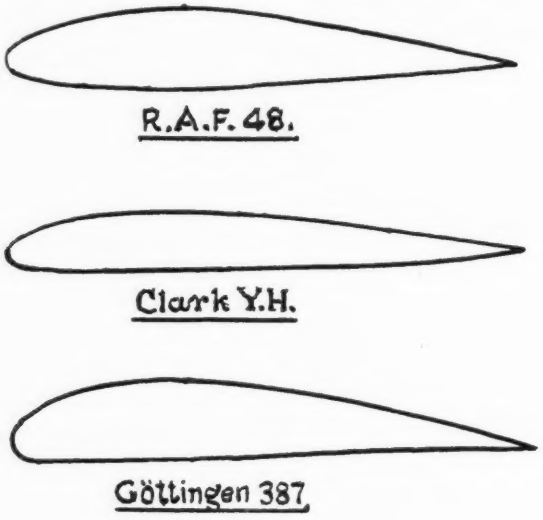

FIG. 8.

In Tables V, VI and VII[76] the same method of calculation is applied to give K_D/K_L directly in col. 4, K_D being given in col. 5. It will be seen that the theoretical graph and the plottings of the data determined experimentally (taken from the Report) are in fair agreement for low and moderate values of K_L. For high values the experimental values of K_D show an increase, indicating inferior performance. Ultimately the " burble point " is reached when the system of flow breaks down. The author's theory makes no attempt to deal with that state of things. The condition of least drag/lift is the point at which a line drawn from the origin is tangent to the graph, and this point, given independently by the theory, is shown in both Figures. At this point the author's Prop. I applies and, as should be the case, the skin-frictional and aerodynamic components of K_D are equal to one another.

[76] In Tables V, VI and VII the higher values of K_L are entered first, in order to correspond with plottings.

§35.

TABLE II.

Data.

R.A.F. 48, p. 14, No. 2. $\mathbf{N}_R = 4.58 \times 10^6$.
$a/2\,A = 0.106$. $2\,\mathbf{C}_o = 0.0029$.

1 K_L	2 K_L^2	3 $K_L^2 \times .106$	4 $+.0029 = K_D$	5 K_D observed	6 Efficiency %
0.105	0.0110	0.00116	0.00406	0.0044	93
0.187	0.0350	0.00371	0.00661	0.0070	94.5
0.270	0.0730	0.00774	0.01064	0.0111	96
0.351	0.1260	0.01335	0.01625	0.0169	96.2
0.428	0.183	0.01940	0.02230	0.0241	92.5
0.505	0.255	0.02700	0.02990	0.0327	91.5
0.578	0.334	0.03540	0.03830	0.0423	90.5
0.645	0.417	0.04420	0.04710	0.0531	88.6

For plotting see Fig. 9.

TABLE III.

Data.

Clark Y.H., p. 22, No. 1. $\mathbf{N}_R = 4.43 \times 10^6$.
$a/2\,A = 0.106$. $2\,\mathbf{C}_o = 0.0029$.

1 K_L	2 K_L^2	3 $K_L^2 \times .106$	4 $+.0029 = K_D$	5 Observed	6 Efficiency %
0.126	0.0159	0.00169	0.00459	0.0051	90
0.209	0.0435	0.00460	0.00750	0.00815	92
0.288	0.0830	0.00880	0.01170	0.0127	92.2
0.370	0.137	0.01452	0.01742	0.0188	92.7
0.447	0.200	0.02120	0.02410	0.0264	91.5
0.523	0.274	0.02905	0.03195	0.0355	90.0
0.595	0.354	0.03750	0.04040	0.0459	88.1

For plotting see Fig. 10.

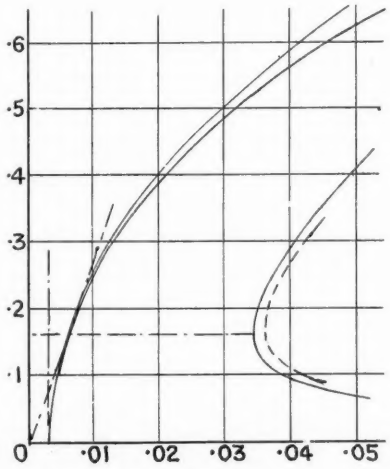

FIG. 9.
Plotting from Table II.

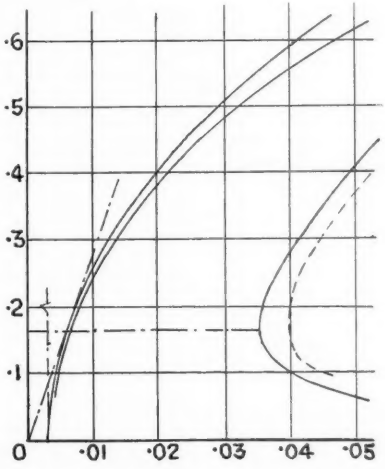

FIG. 10.
Plotting from Table III.

TABLE IV.

Data.

Göttingen, p. 26, No. 2. $\mathbf{N}_R = 4.37 \times 10^6$.
$a/2A = 0.106$. $2\mathbf{C}_o = 0.0029$.

1 K_L	2 K_L^2	3 $K_L^2 \times .106$	4 $+.0029 = K_D$	5 K_D observed	6 Efficiency %
0.061	0.00375	0.00040	0.0033	0.0049	67.3
0.184	0.0340	0.00360	0.00650	0.0085	76.5
0.302	0.0910	0.00965	0.01255	0.0143	87.8
0.418	0.1750	0.01860	0.02150	0.0238	90.4
0.529	0.2800	0.02960	0.03250	0.0365	89.0
0.631	0.398	0.04220	0.04510	0.0522	86.4

For plotting see Fig. 11.

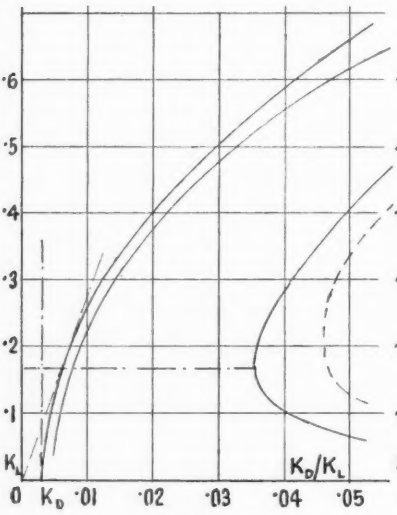

FIG. 11.
Plotting from Table IV.

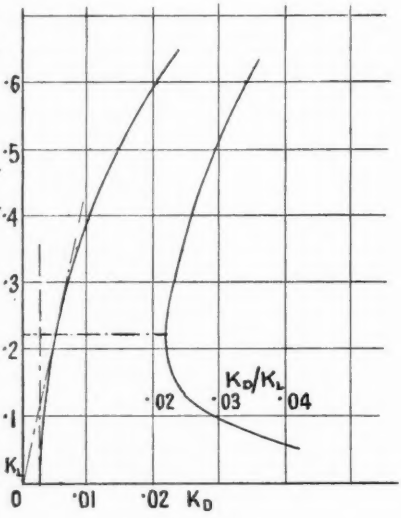

FIG. 13.
Plotting from Table VIII.

§36. *Application.—Example.*—R. and M. 1627, p. 14, Table I, section R.A.F. 48, model aerofoil, span = 4 ft., chord = 0.666 ft., n = 6. Reynolds number as given, $\mathbf{N}_R = 3.56 \times 10^6$.

TABLE V.

Data.

$a/2A = 1.27/(2 \times 6) = 0.106$. $\mathbf{C}_o$ from graph = 0.0015
or $2\mathbf{C}_o = 0.003$.

1 K_L	2 $K_L \times .106$	3 $+.003/K_L$ =	4 (K_D/K_L) ×	5 $K_L = K_D$
0.5	0.0530	0.0060	0.0590	0.02950
0.4	0.0424	0.0075	0.0499	0.01996
0.3	0.0318	0.0100	0.0418	0.01254
0.2	0.0212	0.0150	0.0362	0.00724
0.168	0.0178	0.0178	0.0356	0.00600
0.1	0.0106	0.0300	0.0406	0.00406

Again, p. 15, Table II, section R.A.F. 48, model aerofoil, span = 4 ft., chord = 0.666 ft., n = 6. Reynolds number as given, $\mathbf{N}_R = 6.72 \times 10^6$,

TABLE VI.

Data.

$a/2A = 0.106$ (as before). C_o from chart = 0.0014
or $2C_o = 0.0028$.

1	2		3		4		5
K_L	$K_L \times .106$	+	$.0028/K_L$	=	(K_D/K_L)	×	$K_L = K_D$
0.5	0.0530		0.0056		0.0586		0.02930
0.4	0.0424		0.0070		0.0494		0.01976
0.3	0.0318		0.0093		0.0411		0.01233
0.2	0.0212		0.0140		0.0352		0.00704
0.162	0.0172		0.0172		0.0344		0.05600
0.1	0.0106		0.0380		0.0386		0.00386

Again, p. 22, Tables I and II, section Clark Y.H., model aerofoil, 4 ft. span, 0.666 ft. chord, $n = 6$. Reynolds number as given, $N_R = 4.43$ and 5.59 respectively. Giving $C_o = 0.00145$ or $2C_o = 0.0029$.

$a/2A$ as before = 0.106.

TABLE VII.

1	2		3		4		5
K_L	$K_L \times .106$	+	$.0029/K_L$	=	(K_D/K_L)	×	$K_L = K_D$
0.5	0.0530		0.0058		0.0588		0.02940
0.4	0.0424		0.0072		0.0496		0.01984
0.3	0.0318		0.0097		0.0415		0.01245
0.2	0.0212		0.0145		0.0357		0.00714
0.165	0.0175		0.0176		0.0351		0.00580
0.1	0.0106		0.0290		0.0306		0.00396

Plottings of the foregoing examples are given in Fig. 12. For the purpose of comparison in Fig. 12 the actual experimental values are given plotted as in Fig. 3 of the Report.

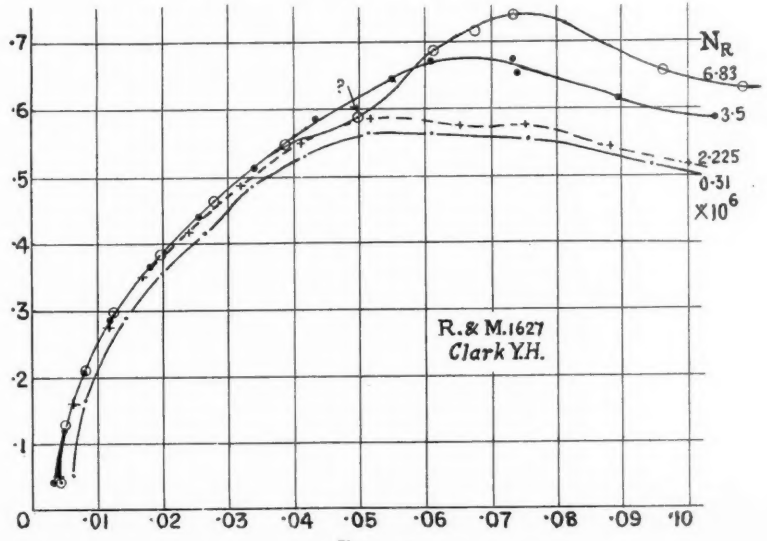

FIG. 12.

Plotting from Fig. 3, R. and M. 1627.

§37. *The Limit of Performance.*—In order to forecast the practical limiting value, the minimum value of K_B/K_L, we will specify a machine, a monoplane, aspect ratio $\mathfrak{n} = 10$, and of 14 tons gross weight = 31,000lbs., $W = 1{,}000{,}000$ poundals, designed with a flight speed (least resistance) 300 ft./sec., approximately 200 m.p.h. We shall assume the aerofoil to be of elliptic plan form. Thus, $a/2A = 0.05$, $\mathbf{N}_R$[77] $= 1.6 \times 10^7$ from which $2\,\mathbf{C} = 0.0024$,[78] K_L (opt.) $= \sqrt{(0.0024/0.05)} = 0.219$.

TABLE VIII.

1	2	3	4	5	6	7	8
K_L values	x .05	$.0024/K_L$	$R/W = K_D/K_L$	K_D	Drag (poundals) $W=10^6$	Drag (pounds) $g=32.2$	V ft. sec.
0.10	0.0050	0.024	0.0290	0.0029	29,000	900	448
0.15	0.0075	0.016	0.0235	0.0035	23,500	730	365
0.20	0.0100	0.012	0.0220	0.0044	22,000	683	317
0.219	0.0109	0.0109	0.0218	0.00477	21,800	677	300
0.25	0.0125	0.0096	0.0221	0.0055	22,100	687	282
0.30	0.0150	0.0080	0.0230	0.0069	23,000	715	257
0.35	0.0175	0.0068	0.0243	0.0085	24,000	745	238
0.40	0.0200	0.0060	0.0260	0.0104	26,000	807	224

For plotting see Fig. 13.

Strictly speaking, under the condition W = const. and V variable, the value of $\mathbf{N}_R$ given only applies for K_L (opt.) for other values of K_L, $\mathbf{N}_R$ will vary as V, and $\mathbf{C}_o$ will vary accordingly. For high values of $\mathbf{N}_R$ this does not need to be considered. Compare Part V.

Taking the designed flight speed 300 ft./sec. (condition of least resistance), namely, $K_D = 0.00477$,

$$\text{the area } a = 21{,}800/(0.00477 \times 300^2 \times 0.078) = 650 \text{ sq. ft.},$$
$$A = 6{,}500.$$

This gives the containing rectangle = 830 sq. ft., namely, the chord = $\sqrt{83}$ = 9.1 ft. and the span = 91 ft. Alternatively, we may calculate the area a from the value of K_L (opt.) thus,

$$a = 1{,}000{,}000/(0.219 \times 300^2 \times 0.078) = 645 \text{ sq. ft.}^{79}$$

The flight speeds given in column 8 are based on this figure (650 sq. ft.) and the constant K_L; thus,

$$V = \sqrt{(W/K_L \rho a)} = \sqrt{\{1{,}000{,}000/(K_L \times 0.078 \times 650)\}}$$

§38. Having dealt with the aerofoil, we may next deal with the body resistance. It will be assumed that the needed accommodation can be provided in a fusiform body of circular section 10 ft. dia., the distance from nose to "wash out" not to exceed 5 diameters (= 50 ft.) the constant = 15×0.0015 on basis of maximum cross-sectional area. Thus, resistance at 300 ft./sec. = $15 \times 0.0015 \times 0.078 \times 78.5 \times 300^2 = 12{,}400$ poundals = 385 pounds, body resistance at normal flight speed. This is assuming the body form to be that of minimum resistance, without allowance for excrescences of any kind. Since a projecting normal plane of only three sq. ft. would *double* the resistance, it is doubtful whether an allowance of less than 700 pounds for body drag would be sufficient even with every possible precaution taken. It would thus appear that in a fast flying machine such as under consideration the body resistance is as important a factor as contributing to drag as is the flight resistance proper.

[77] If taken from Fig. (Appendix II) on the basis of 31,000lbs. $\mathbf{N}_R = 1.55 \times 10^7$.
[78] In all probability too low: we are wearing the "rose-coloured spectacles."
[79] The difference, less than 1 per cent., is in part due to the use of the slide-rule and in part to the figures not having been taken beyond the third significant figure.

As concerns the ancillary surfaces, the tail plane, elevator flaps, rudder, etc., it is not possible to calculate these until an actual design is on paper and otherwise approved. But for preliminary calculations it may be taken that these organs have an area equal to 25 per cent. of the aerofoil and that their resistance is entirely a matter of skin-friction. On this basis the allowance will be represented by an area 325 sq. ft. of single surface, thus the resistance of added drag[80] will be

$$0.0013 \times 0.078 \times 325 \times V^2 = 0.0325\ V^2$$

or, at the speed of least resistance,

$$0.0325 \times 90{,}000 = 2{,}920 \text{ poundals} = 90.7 \text{ pounds.}$$

§39. The total resistance or drag at designed speed is therefore

$$677 + 700 + 91 = 1{,}468 \text{ pounds,}$$

and the thrust h.p. for horizontal flight

$$= (1{,}468 \times 300)/550 = 800 \text{ h.p.}$$

With due allowance for propeller efficiency this would indicate 1,100 to 1,200 b.h.p. as the minimum provision on which such a machine could sustain itself in horizontal flight. The fuel consumption would be not less than 400 lbs. per hour. On this basis, in order to permit of a 3,000-mile non-stop flight (without re-fuelling) the time of flight would be 15 hours and the weight of fuel 6,000 lbs. or approximately 20 per cent. of the gross weight. It is such a machine that would be the minimum necessary to establish a passenger service across the Atlantic at a single "hop." There is a margin in the fact that the load and therefore the resistance diminishes as the flight proceeds. Also the initial load of fuel oil might well exceed 20 per cent. of the gross. There are further possibilities opened up by flying at high altitude.[81]

This is not the occasion to carry the matter further, but it may be pointed out that if a machine for such a service should need to be furnished with provision for alighting on the water, the direct body and hull resistance will be considerably in excess of that estimated.

Part V.

Application: At Lower Reynolds Numbers.

The sail-plane, a border-line case. Bird flight and the Reynolds number. Models used by the author. An example subjected to analysis: discrepancies discussed. The author's 1894 aerofoil: data and N.P.L. test figures: analysis and comparison. Early R.A.F. models tested at the N.P.L.: data given, and efficiencies calculated.

§40. In its application to cases in which the Reynolds number is less than 10^6 the author's theory does not yield results of the same exactitude as for higher values. Fortunately in aerial navigation, whether it be by aeroplane or airship, we are not much concerned with Reynolds numbers as low as, or lower than, 10^6. Even in the case of the so-called "sail-plane" the value of N_R is commonly in the region[82] of 1 to 2×10^6, and so comes almost within the author's arbitrary definition of a "high" Reynolds number.[83]

Prior to the introduction of the compressed air tunnel, the model work done at the N.P.L. at the instance of the Advisory Committee (of which the author was once a member) and subsequently by the Aeronautical Research Committee,

[80] The value of $C_0 = 0.0013$ assumed is higher than that taken for the aerofoil owing to the lower value of N

[81] See Appendix IV and V.

[82] Example: Chord = 4ft.; V = 54ft. sec. Then $N = (4 \times 54)/.000154 = 1.4 \times 10^6$.

[83] §31.

came " far down the list "; values of N_R below 10^5 were the rule rather than the exception.[84] In the author's early work the same is true, he was often working at values below 10^4. We find no reference to the " Reynolds number " in the early reports (R. and M.); the term was not known in those days, but an equivalent basis of comparison was in use.[85]

§41. It has been stated that inconsistencies are met with when dealing with low values of the Reynolds number. This gave the author some trouble when preparing his work for publication in the years prior to 1907. Now we know more about the conditions governing skin-friction, the position can be better understood. In the author's published table for the weight per sq. ft. proper to least gliding angle, " Aerodynamics," p. 271, we find that at 60 ft./sec. for aspect ratios such as used in the modern " sail-plane " (usually greater than 10) the pressure with a skin-frictional coefficient $\xi = 0.01$ (the corresponding value[86] of $\mathbf{C}_o$ is 0.003) is given as 3.07 pounds per sq. ft. This is about that actually used. This value of $\mathbf{C}_o$ is above the datum graph drawn to represent the minimum for the value of $\mathbf{N}_R$ in question,[87] but it is nevertheless well within the range of the determinations plotted. Again in " Aerodynamics," Table VI, minimum gliding angles are given for values of $\mathbf{n}$ and ξ. For the same coefficient of skin-friction these values are 1 : 22 for aspect ratio = 10 to 1 : 23.9 for aspect ratio = 12. These compare with declared figures as follows:—[88]

British " Falcon III " ...	...	...	1 : 20	approx.
" Cambridge II "	...	...	1 : 20	,,
" Kirby Kite " ...	...	...	1 : 25	,,
" Rhonsperber "	...	...	1 : 23	,,

This agreement would suggest that 1.4×10^6 may be regarded as a high Reynolds number.

Referring to Fig. B in Appendix II, the value of $\mathbf{N}_R$ for a gross weight = 500 lbs. and $\mathbf{n} = 14$ is 1.5×10^6, against the figure 1.4×10^6 already given based on measurement.

§42. When $\mathbf{N}_R$ is less than 10^5 the agreement between results derived from theory and experiment is not so good, and below 10^4 the difference becomes very marked. Amongst birds,[89] even the larger soaring birds, the value of N_R rarely exceeds 2×10^5, yet some of the relations deduced by theory appear to hold good with reasonable exactitude, though it is hard to say with certainty, few writers give much exact information as to weight or flight velocity,[90] and ornithologists

---

[84] R. & M. 110, 1913-14, pp. 94, 99 and 100. $N_R = 1.3$ to 1.6×10^4.

[85] Before the *term* " Reynolds number " came into use, which was about the year 1924, the basis of comparison was often expressed as LV. It being legitimate to regard the kinematic viscosity of air as constant, this really amounted to the same thing as making use of the Reynolds number. Actually the author was the first to deduce and apply the expression LV/ν in connection with the dynamics of flight (see " Aerodynamics," §38).

[86] See footnote §33; $0.6\,\xi = 2\mathbf{C}_o$ or $\mathbf{C}_o = 0.3\,\xi$.

[87] $\mathbf{N}_R = 1.4 \times 10^6$.

[88] As stated. See Programme, R.Ae.S. Garden Party, 10th May, 1936. These figures *presumably* include body resistance. On the other hand the aspect ratio is often greater than 12.

[89] It is not easy to determine the normal flight speed of a bird of any particular species. The fact that the Reynolds number forms a connecting link between *weight* and *velocity* is sometimes a great help, for the *weight* and the *wing plan-form* and *aspect ratio* can be ascertained from the dead bird as shot, and the normal flight velocity inferred with a reasonable degree of certainty.

[90] A notable exception is that of the French writer Mouillard.

never.[91] In the gliding models on which the author had to rely the value of N_R was usually between 10^3 and 10^4. Owing to the high values of C_o at these low Reynolds numbers the flight performance was certain to be inferior, but in fact, so far as the author was able to ascertain it was invariably worse than theory would lead one to expect, in brief, the efficiency was low. The gliding angle, the best the author could obtain, was in many cases twice as steep as should have been the case, that is to say, the minimum value of K_D/K_L was far too high. This is illustrated in the following examples, analysed by the methods which will now be familiar.

Author's Models.

§43. In his early investigations the author, so far as experiment was concerned, had, by force of circumstances, to confine himself to working on a small scale and at low velocities, the largest of the models used for quantitative determinations (Fig. 14) weighed no more than 12.3 grams = 0.0267 lb. Thus W = 0.86 pdls.[92]

By measurement, $\mathbf{N}_R = 10^4$. Thus, the chord measurement = 0.166 ft.; V (as measured) = 9.3 ft./sec.

$$N_R = (0.166 \times 9.3)/0.000154 = 10{,}000.$$

On the basis of weight (see Fig. C, Appendix II) $\mathbf{N}_R = 8.0 \times 10^3$ which is sufficiently close to the measurement value to justify either method of calculation being employed.

The reason that there is any discrepancy at all, except for a little uncertainty as to the value of C_o,[93] is that the measured velocity 9.3 ft./sec., which was the natural velocity of this model, may not have been precisely the velocity of least resistance. That the difference should be so small is a remarkable testimony to the care with which the experimental work was done; at that time the author had not even considered that a relation might exist between the dimensionless group Vl/ν (now known as the Reynolds number) to the lifting reaction W.

We will now submit this model to the ordeal of an analysis on the lines already established.

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[91] To judge from the books written by ornithologists it might be imagined that the writers were unaware that *birds fly*, no mention is made of the data relating to the function of flight. The weight of the adult bird is rarely given, almost by accident if at all. The normal flight velocity, if stated (which is rare) is usually wrong, and often absurd. The sail plan is never given, for that one has to go to Mouillard. No observations are forthcoming on the important subject of gliding angle, and so on, the list is by no means exhausted. But the pretty colours of the plumage are described in detail. also some of the seeds that are found in its "little inside," and the descriptions are written in an imitation of literary style, the writers studiously avoiding anything in the way of tabular form or logical order. Each article has to be read from end to end to make sure that the information wished for is not there (it usually is not). In brief, the typical ornithologist seems to combine in one personality a power of observation equal to that of an immature child with a varied capacity of expression worthy of a professional journalist. The entomologist dealing with insects that fly is often not much better.

[92] The larger models weighed 1¼ to 1½lbs. "Aerial Flight," Vol. II, Figs. 15, 16 and 17. These had for their primary purpose to demonstrate the principles of stability. Such models with their relatively high speed of flight are not easily made the subject of exact aerodynamic measurement. Even then the value of N_R was considerably less than 10^5.

[93] This would affect the weight relation, but not that derived from measurement.

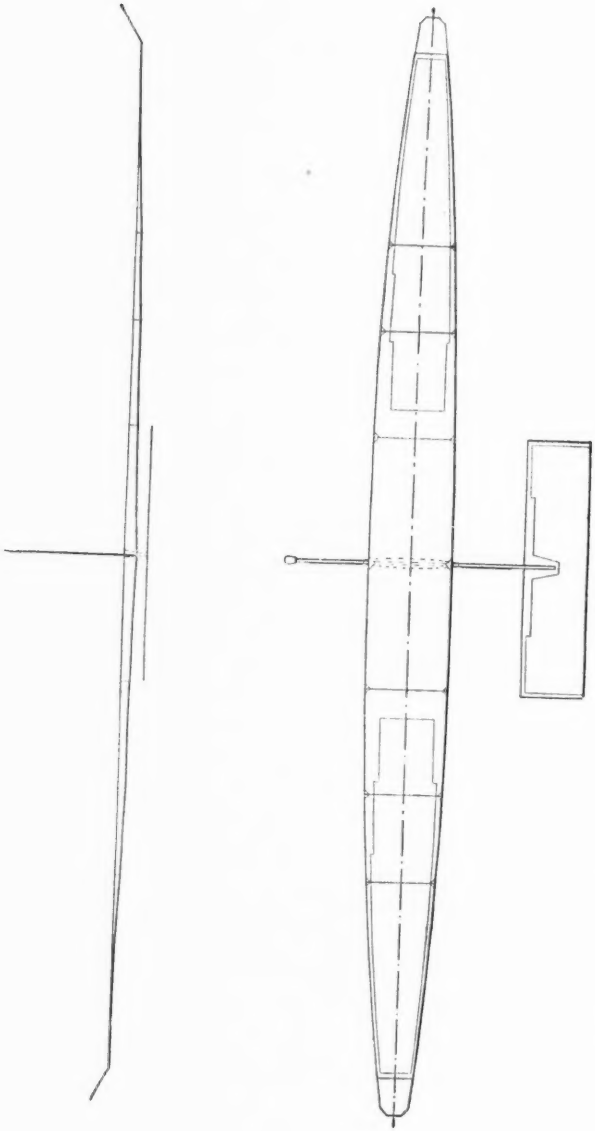


FIG. 14.

Scale drawing of mica glider, the subject of analysis ("*Aerial Flight*," *Vol. II, Fig.* 60).

§44.

TABLE IX.

Data.

Mass 12.3 grams = 0.027 lb., $W = 0.87$ poundals, $S = 2.2$ ft., chord $L = 0.166$ ft., $\mathbf{n} = 13$, $\mathbf{N}_R = 10^4$ (@ $V = 9.3$ ft./sec.), $\mathbf{C}_o = 0.0069$ (App. II), $A = 3.7$, $a = 0.285$, $2A/a = 26$, $a/2A = 0.038$.

1 K_L	2 V	3 $\mathbf{N}_R$	4 $\mathbf{C}_o$	5 $K_L \times (a/2A)$	6 $2\mathbf{C}_o/K_L$	7 K_D/K_L
0.60	9.2	1×10^4	0.0070	0.023	0.0233	0.0463
0.55	9.4	1.02×10^4	0.0068	0.021	0.0246	0.0456
0.50	9.9	1.07×10^4	0.0067	0.019	0.0268	0.0458
0.45	10.4	1.13×10^4	0.0065	0.0172	0.0290	0.0462
0.40	11.0	1.19×10^4	0.0063	0.0153	0.0316	0.0469
0.35	11.8	1.28×10^4	0.0068	0.0134	0.0344	0.0478
0.30	12.8	1.39×10^4	0.0058	0.0115	0.0387	0.0502

For plotting see Fig. 15.

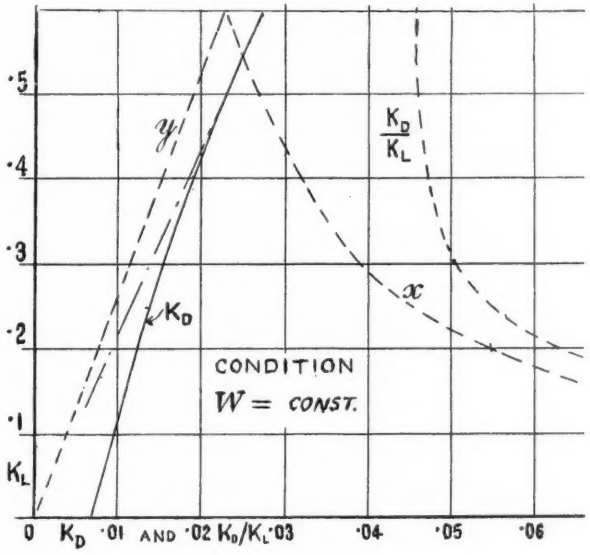


FIG. 15.

Plotting from Table IX.

It is important to observe in this table that the minimum value of K_D/K_L (column 7) does not coincide with equality between the aerodynamic resistance (column 5) and the direct skin-frictional resistance (column 6) as it should in accordance with the author's Prop. I. This is because at low values of N_R the value of $\mathbf{C}_o$ is no longer sensibly constant, the index n in the expression $R \propto V^n$ is now less than 2, so that the assumption on which the proposition is based is no longer exact. This is discussed more fully in Appendix IV.

Table IX relates to a glider in free flight, when W is constant and V the variable. If it had related to determinations made in the wind tunnel with V constant and W the variable the point would not have arisen.

The actual value of K_L as determined by the area a, force W and velocity V, is

$$K_L = 0.86/(0.078 \times 86.5 \times 0.28) = 0.457$$

at which it will be seen $K_D/K_L = 0.046$. The actual gliding angle as measured ("Aerial Flight," Vol. II, p. 118) = 0.13, which would suggest an efficiency of only 35 per cent. However, the auxiliary surfaces have to be taken into account and allowance made. The total tail and fin area amounted to 0.122 sq. ft. or the "wetted" surface 0.224. This will account for 0.015 pdl. to be deducted from the resistance observed, thus, $(0.87 \times 0.13) - 0.015 = 0.098$ and the observed aerofoil K_D/K_L as corrected is $0.098/0.87 = 0.112$ and the efficiency is $0.046/0.112 = 41$ per cent. It might well be as high as 45 per cent. since no account has been taken of the resistance of the "back-bone" and certain other detail components which it is impossible to assess.

With values of $\mathbf{N}_R = 10^6$ and upwards it has been shown that efficiencies of over 90 per cent. may be reached. The above is typical of the poor performance commonly associated with low values of $\mathbf{N}_R$. The difference cannot be attributed as directly due to the higher values of the skin-frictional constant $\mathbf{C}_o$, for this has been taken into account. It appears to be consequent upon some kind of degeneration in the peripteral dynamic system; some light is shed on this by the example which follows.

The Author's 1894 Aerofoil.[94]

§45. Although the author was not able himself to measure either the K_D or the K_D/K_L ratio of the aerofoil of his 1894 gliding model, this was done nearly twenty years later (1913) in Göttingen, also at the N.P.L.

At that date the only wind channel available at the N.P.L. was not of sufficient capacity to deal with the actual aerofoil and the determinations were made from a three-quarter scale model. The wind velocity was 30 ft./sec. The results of the tests are given in R. and M. No. 109,[95] from which the figures given in Table X are quoted. The last two columns have been added as derived.

Table X.

Lift Coefficient K_L taken at 30ft. sec.	K_L/K_D	K_D/K_L	K_D
0.066	6.3	0.1590	0.0105
0.143	13.0	0.0770	0.0110
0.234	17.1	0.0585	0.0137
0.305	15.2	0.0660	0.0201
0.366	11.7	0.0855	0.0313
0.399	8.1	0.1233	0.0492
0.401	6.4	0.1560	0.0626

In the report it was stated that had the tests been made at the velocity specified, namely, 50 ft./sec., the maximum value for lift/drag would have been 20 or 21 instead of 17.1 as measured. Without this allowance the figure was higher than anything at that date on record.

An analysis of this model is given in Table XI. Being a wind tunnel test, the velocity was constant, namely, 30 ft./sec., so that it is not necessary to make any allowance[96] for variation of $\mathbf{N}_R$ or $\mathbf{C}_o$.

§46. *Data.*—Span $S = 2.5$ ft., chord (max.) = 0.187 ft., mean = 0.140 ft., $\mathbf{N}_R$ calculated on basis of mean chord $= 2.80 \times 10^4$, $\mathbf{N}_R$ based on weight[97] approx. 2.5×10^4, $\mathbf{C}_o = 0.0044$, $A = 4.9$ sq. ft., $a = 0.37$ sq. ft., $2A/a = 26.6$, $a/2A = 0.0375$. By formula, K_L (opt.) $= 2\sqrt{(0.0044 \times 13.3)} = 0.484$.

[94] One of the original aerofoils is now preserved in the Science Collection, South Kensington Museum.

[95] Advisory Committee, Technical Reports, 1913-14, p. 87.

[96] It might be thought that when W is a variable the value of $\mathbf{N}_R$ taken on a basis of weight (Appendix II) must vary also, but this is not so, the weight basis relates to the condition of least resistance.

[97] Fig. 21, Appendix II.

Actually in the wind tunnel (Table X) the optimum value of K_L is in the region of 0.234. Table XIA shows clearly that for higher values of K_L there is a rapid falling off in efficiency; this we have learned to attribute to the breakdown in the peripteral system of flow, the "burble" point is reached far below the value of K_L at which the minimum value of K_D/K_L would otherwise be found. In the plotting we see a fair approximation (not too good) for low values of lift, and then an early break away, of the same character as appears in Fig. 15, but much exaggerated. The lower the Reynolds number the earlier the break-away appears.

TABLE XIA.

1	2	3	4	5	6	7
K_L	$\times .038$	$.0088/K_L$	K_D/K_L	Calcul. K_D	Actual (N.P.L.) K_D	Efficiency %
0.401	0.01520	0.0220	0.0372	0.01490	0.0626	24
0.399	0.01513	0.0221	0.0372	0.01482	0.0490	30
0.366	0.01385	0.0241	0.0379	0.01385	0.0313	44
0.305	0.01155	0.0289	0.0404	0.01233	0.0200	61
0.234	0.00885	0.0376	0.0464	0.01085	0.0137	79
0.143	0.00550	0.0615	0.0670	0.00960	0.0110	87
0.066	0.00250	0.1330	0.1355	0.00895	0.0105	85

For plotting see Fig. 16.

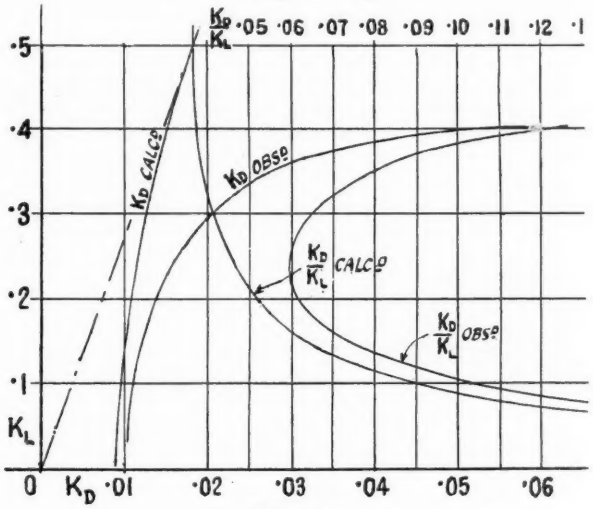


FIG. 16.

Plotting from Table XIa.

TABLE XIB.

K_L	K_L/K_D Calculated	Observed
0.401	26.9	6.4
0.399	26.9	8.1
0.366	26.4	11.7
0.305	24.8	15.2
0.234	21.6	17.1
0.143	15.0	13.0
0.066	7.4	6.3

§47. In spite of the fact that this aerofoil constituted a record at the time the tests were made, it does not show up particularly well on analysis. That the critical condition or " burble point " was reached at far too low a value of K_L is shown both by the early and rapid falling-off of efficiency, and the fact that K_L reached its maximum at 0.401. It may be inferred that the form of section had not sufficient camber, also it is probable that the leading edge was too knife-like—such a feature tends to limit the range of K_L values that may be usefully employed. To what extent the poor performance can be attributed specifically to these causes, and to what extent to the secondary influence of the low Reynolds number, it is not possible to say. However, the graph up to the value $K_L = 0.234$ is not bad, the efficiency is reasonably high; it is probable that a part of the deficiency at higher values is a characteristic of the condition of laminar flow. A micro-turbulent condition is necessary to cause the stream to follow the upper surface of the aerofoil, without turbulence there is always a tendency to break away. This fact was brought clearly to light in the celebrated experiment of Prandtl when he was able to effect a great reduction in the resistance of a sphere by inducing a condition of turbulent flow by means of a wire ring fixed to the surface of the sphere itself.[98]

This view accords with the fact that the higher the value of $\mathbf{N}_R$, and the further we are from the condition of laminar flow, the higher becomes the value of the lift constant K_L available, the onset of the condition of " burble " is postponed. This should give food for thought to those who would endeavour to cultivate laminar flow by perfection of surface, the possibility of which is in any case doubtful.[99]

It is the author's opinion that this is the clue to the nature of the *secondary effect* of the low Reynolds number. The primary effect is the higher value of the constant $\mathbf{C}_o$ which tends to produce a direct increase of drag; the secondary effect is the separation of the system of flow from the upper surface of the foil due to the fact that laminar flow is taking the place of the micro-turbulent condition.

§48. *Analysis of Model Aerofoil R.A.F. 6.*[100]—Save as concerns aspect ratio and plan form this model is comparable to the preceding example (section profile Fig. 17).

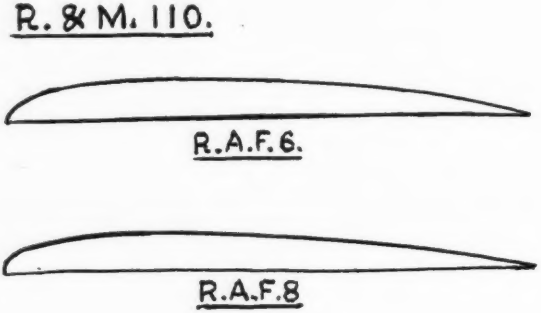


FIG. 17.

Data.

L (chord dimension) = 0.21 ft.
V = 30 ft./sec. (middle column)
$\mathbf{N}_R = 0.21 \times 30/0.000154 = 4.1 \times 10^4$.

This is too high a value for fair comparison.

[98] See Technical Reports, Advisory Committee for Aeronautics, 1915-16, pp. 21, 22.
[99] Proc. Royal Institution of G.B., Vol. 28, Part IV, No. 135. Discourse by Professor Melvill Jones; pp. 648 *et seq.*
[100] R. & M. 110, 1913-14, p. 100; Table 12.

If V be taken = 20 ft./sec., $\mathbf{N}_R = 0.21 \times 20/0.000154 = 2.73 \times 10^4$, substantially the same as in the author's model; it will therefore be taken as a basis.

$\mathbf{C}_o$ effective (from graph + 25 per cent.) = 0.0045 or $2\,\mathbf{C}_o = 0.009$, $\mathbf{n} = 6$; plan form rectangular, $a/2A = 1.27/12 = 0.106$.

TABLE XII.[101]

R. and M. 110, 1913-14, pp. 99 and 100, at 20 ft./sec.

1	2	3	4	5	6	7	8
			$+2\mathbf{C}_o$	K_D	Efficiency	Observed	
K_L	K_L^2	$\times .106$	$(=.009)=K_D$	observed	%	K_D/K_L	K_L/K_D
0.576	0.332	0.0352	0.0442	0.0689	64	0.120	8.37
0.529	0.280	0.0297	0.0387	0.0579	67	0.110	9.15
0.471	0.222	0.0235	0.0325	0.0440	74	0.093	10.70
0.415	0.172	0.0182	0.0272	0.0350	78	0.084	11.85
0.348	0.121	0.0128	0.0218	0.0276	79	0.079	12.60
0.265	0.070	0.0074	0.0164	0.0210	78	0.079	12.60
0.147	0.0216	0.0023	0.0113	0.0163	69	0.110	9.00
0.070	0.0049	0.0005	0.0095	0.0163	58	0.233	4.30

For plotting see Fig. 18.

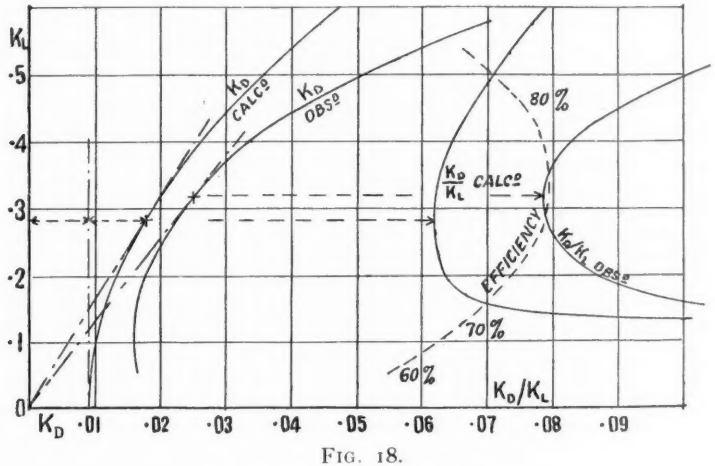


FIG. 18.

Plotting from Table XII.

§49. As illustrating the rapidity with which performance falls off at still lower values of $\mathbf{N}_R$, an analysis of the same aerofoil at V = 10 ft./sec. is given in Table XIII.

$\mathbf{N}_R = 2.1/0.000154 = 1.36 \times 10^4$ at which the constant $\mathbf{C}_o$ read from the chart (+ 25 per cent.) = 0.0058 or $2\,\mathbf{C}_o = 0.0116$, $A = 0.265$, $\mathbf{n} = 6$, $a = 0.264$, $a/2A = 0.106$, $2A/a = 9.45$.

[101] This Table is illuminating: the lower efficiency at lesser values of K_L and the higher efficiency at greater values, suggests that the sectional form is better adapted to heavy loading than in the case of the author's 1894 model.

TABLE XIII.

R. and M. 110, 1913-14, pp. 99 and 100, at 10 ft./sec.

1	2	3	4	5	6	7	8
			$+2C_0$	K_D	Efficiency	Observed	
K_L	K_L^2	$\times .106$	$(=.0116)=K_D$	observed	%	K_D/K_L	K_L/K_D
0.475	0.226	0.0240	0.0356	0.0568	62.7	0.117	8.5
0.413	0.170	0.0180	0.0296	0.0444	67.0	0.107	9.3
0.322	0.1035	0.0110	0.0226	0.0342	66.2	0.106	9.4
0.204	0.0416	0.0044	0.0160	0.0265	60.5	0.130	7.7
0.140	0.0196	0.00208	0.0137	0.0210	65.2	0.150	6.7
0.075	0.0056	0.00059	0.0122	0.0187	65.2	0.250	4.0

For plotting see Fig. 19.

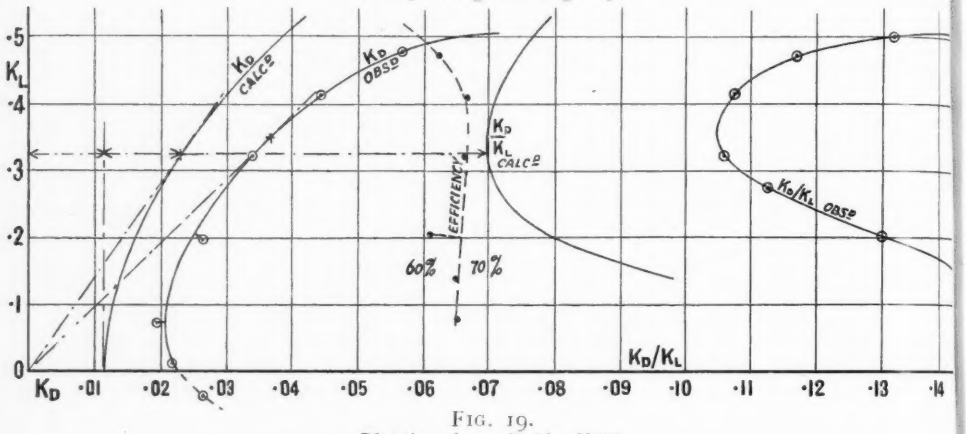


FIG. 19.
Plotting from Table XIII.

The irregularities in Table XIII are probably due to experimental inaccuracy, the forces both lift and drag on such a model at 10 ft./sec. are very small. The same applies generally to K_L values less than about 0.10.

§50. An analysis may now be given for comparison showing the performance of R.A.F. 8. The data are taken from the Technical Report of the Advisory Committee for the year 1913-14.[102] Size of the model 1.5×0.25 ft., plan form rectangular. Profile Fig. 17. The velocity is given as 40 ft./sec.

L (chord dimension) = 0.25 ft.
V = 40 ft./sec.
} $\mathbf{N}_R = 65{,}000 = 6.5 \times 10^4$.

$\mathbf{C}_0$ = (effective) = 0.0035, $\mathbf{n}$ = 6, $a/2A = 1.27/12 = 0.106$, $2\mathbf{C}_0 = 0.007$.

TABLE XIV.

1	2	3	4	5	6	7	8
			$+2C_0$	K_D	Efficiency	K_L/K_D	
K_L	K_L^2	$\times .106$	$(=.007)=K_D$	observed	%	calc.	obs.
0.520	0.2700	0.0286	0.0356	0.0844	42	14.6	6.2
0.552	0.3050	0.0324	0.0394	0.0504	78	14.0	11.0
0.497	0.2470	0.0262	0.0332	0.0401	83	15.0	12.4
0.432	0.1870	0.0198	0.0268	0.0319	84	16.1	13.6
0.360	0.1300	0.0138	0.0208	0.0240	87	17.3	15.1
0.287	0.0825	0.00875	0.0157	0.0177	87	18.3	16.2
0.202	0.0408	0.00433	0.01133	0.0148	76.5	17.8	13.7
0.086	0.0074	0.00078	0.00778	0.0155	50	11.1	5.6

For plotting see Fig. 20.

[102] Table 4, p. 94.

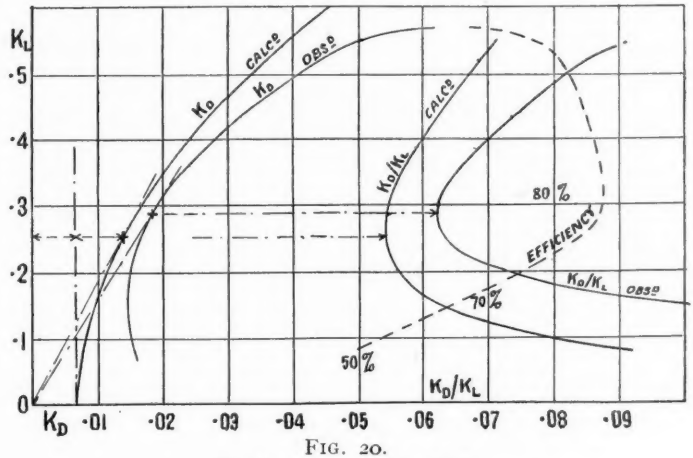


FIG. 20.
Plotting from Table XIV.

The derived data as above are shown plotted in Fig. 20.

The theoretical optimum K_L (opt.) $= 2\sqrt{(0.0035 \times 4.7)} = 0.256$, which is substantially in agreement with the table.

APPENDIX I.

THE AERONAUTICAL RESEARCH COMMITTEE AND THE REYNOLDS NUMBER N_R.

It is mentioned in the text that whilst accepting the values of N_R given in R. and M. 1627 the author had found a little difficulty in reconciling these with the other data given. The differences are not important; nevertheless an explanation ought to be forthcoming. It seemed desirable to recalculate these values in view of the fact that Reynolds numbers given in many of the previous reports had no relation to the dimension on which skin-friction depends; for example, in the case of airship models the parameter L on which the value of N_R is based, we find defined as the cube root of the volume, and not the length of the model.[103] On this particular point as concerns R. and M. 1627 the author has been able to satisfy himself.

In the case of experiments in the compressed air tunnel the calculation of N_R is not so easy as when experiments are conducted in free air. Allowance has to be made for the density, and this depends partly on the temperature within the pressure chamber; this temperature also affects the viscosity of the air, namely, the value of μ. Unfortunately the Reports do not state the temperature at which the observations were made, and although pressures are given in atmospheres, the report does not define the *atmosphere*, it may be presumed that the latter is the usual standard, expressed in *bars* = 1.01388 or with sufficient precision 14.7 pounds per sq. in. Another point which complicates the matter is that for some obscure reason the Aeronautical Research Committee use the discredited Perry system, in which the pound a *force* is made the fundamental unit, and the slug (mass) a derived unit. Or it may be that the *slug* is defined as fundamental, the unit of mass, and the pound (force) is the derived unit. This is, however, not in accordance with the definitions given by the late Professor Perry.

The *reductions* given at the head of the tables include in each case the value of ρV^2 and the value of V is given, so we have the means of calculating ρ. Thus

[103] R. & M. 607.

$\rho = \{ (\rho V^2) \times 32.2 \} / V^2$ the value of $g = 32.2$ being introduced in order to conform to the usual practice in the matter of units. Then, the corresponding value of ρ, under isothermal conditions, is derived from the pressure given, and the actual ρ divided by the isothermal value gives the relation of the two temperatures absolute. We may take as datum temperature 10°C., at which the density of *dry* air is 0.078 in British units. The figures given relating to aerofoil Clark Y.H. p. 22 of Report 1627, Table 1, are,

Pressure = 15 atmospheres, V = 79 ft./sec., $\rho V^2 = 203.5$.

Proceeding as above:—

$\rho = (203.5 \times 32.2)/6,220 = 6,560/6,220$ or density $\rho = 1.052$.[104]

On the isothermal basis ($\theta_1 = 10$°C.),

$$\rho = 15 \times 0.078 = 1.17.$$

$$\therefore \rho_2 = (1.17/1.052) \times 283 = 315 \text{ C. abs.}$$

$$273$$

$$= 42\text{°C. (107°Fah.)}$$

At this temperature the author has calculated $\mu = 0.000196$ (c.g.s. units) $= 0.0000132$ (ft./lb./sec. units) or, the kinematic viscosity, $\nu = 0.00001244$; ρ being taken = 1.052 as above. So that

N_R the Reynolds number $= (79 \times 0.666)/0.00001244$[105] $= 4.22 \times 10^6$

as compared with 4.43×10^6 given in the report.

By the same method, Table II on the same page, the author finds 5.4×10^6 against 5.49×10^6 given in the Report.

It is possible that the condition of *dry air* was not that on which the "reduction" in the Report was based; but in that case no mention is made of the degree of humidity assumed.

The author cannot refrain from entering a protest against the practice of the Aeronautical Research Committee concerning the manner in which their Reports are presented. He considers that whenever possible the *actual data* as observed and recorded should be issued with the reports. Let these so-called *reductions* be issued by all means. But firstly let us have the *facts*, on which they are based, the "untouched photographs." One example is sufficient to show that this protest is not frivolous or unnecessary. When making an analysis of some of the published figures, the author was brought up short by a report, R. and M. 456, and, after wasting a great deal of time, he wrote to Sir James Peteval for enlightenment. The reply was to the effect that there had been a mistake made, and that an erratum had since been issued. It was a very nice letter, but it ought not to have been necessary. We all make mistakes, but if only the original data were presented we should be able to make our own mistakes, and then if there were "reductions" as well, we should be in a position to check our own mistakes against those of the N.P.L. staff, and so arrive at the truth.

Appendix II.

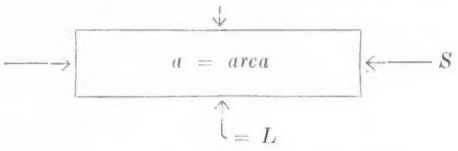
The Reynolds Number in Relation to Gross Weight.

There is some advantage in being able to predict the Reynolds number, and ascertain the value of C_0 before embarking on actual design. In a lecture delivered in May, 1914, the author pointed out that the value of LV could be deduced, independently of measurement, if the gross weight and the aspect ratio of a machine or glider are specified or known in advance. In those days LV was commonly used and stood in place of that which is now termed the Reynolds number, the kinematic viscosity being taken for granted. It is now possible to

[104] All we are doing is to invert the calculation by which the figure 203.5 was initially derived.

[105] The linear parameter 0.666 is the chord dimension of the model aerofoil in feet.

state this relation in more precise terms. The equation connecting $\mathbf{N}_R$ with W (the weight of force) may be derived in the following manner. In the first instance it is assumed that we have to deal with an aerofoil of rectangular plan-form, thus—



$$a = L^2\mathbf{n}$$

Peripteral area $A = S^2 \times \pi/4$; $a = S^2/\mathbf{n}$ $\therefore$ $A/a = \mathbf{n} \times \pi/4$.

$$K_L \text{ (opt.)} = 2\sqrt{(\mathbf{C}_o\mathbf{n} \times \pi/4)} = 1.77\sqrt{(\mathbf{C}_o\mathbf{n})}$$

$$W = K_L\rho V^2 a = 1.77\sqrt{\mathbf{C}_o} \times \mathbf{n}^{1.5} \times V^2L^2\rho$$

$$\text{or } W = \mathbf{N}_R{}^2\sqrt{\mathbf{C}_o} \times 1.77\ \rho v^2 \times \mathbf{n}^{1.5}$$

In solving this equation we take a number of values of $\mathbf{N}_R$ and read from Table A corresponding values of $\mathbf{C}_o$; from this we calculate the values of $\mathbf{N}_R{}^2\sqrt{\mathbf{C}_o}$ and write these down as in column 4 of Table B, which is given by way of illustration. In this table the figure 10^{-8} in column 3 is part of the expression for ρv^2 taken in from Table C. The figure 0.328 at the head of column 5 is the product of the constant 1.77 from equation (2) and the value 0.185 given in Table C for ρv^2 at 10°C. and at sea level. The product (column 5) is then multiplied by the value of $\mathbf{n}^{1.5}$ taken from Table D yielding in column 6 the weight (W poundals) corresponding to the value of $\mathbf{N}_R$ in column 1. Dividing W by g (= 32.2)[106] we obtain, column 7 the *mass*[107] in lbs. For small values this is shown (column 8) converted into grams.

In Figs. 21 and 22 graphs are given to a logarithmic scale for aspect ratios ranging from 6 to 16, even numbers only.

We have yet to consider how to treat aerofoils of other than rectangular plan-form. In this the author prefers to start with a more comprehensive definition of aspect ratio, based on the area of the foil. Using the symbol L as the *mean* chord or fore-and-aft dimension; then $L = a/S$ and $\mathbf{n} = S^2/a$. In the case of rectangular plan-form, this expression does not differ from that ordinarily defined. In the case of the ellipse, where the relation major axis in terms of minor would usually be described as the aspect ratio, the value of $\mathbf{n}$ as now defined is $4/\pi$ or 1.27 times as great. Thus, the author's 1894 model, of elliptic form having an *axis* ratio of 13.3 would be deemed to have an aspect ratio = 17. The same equation applies under this definition as for the rectangular plan-form, we have merely substituted an equivalent rectangle for the actual plan-form whatever that may be.

When we come to deal with figures, the first step is to tabulate the values of $\mathbf{C}_o$ as a function of $\mathbf{N}_R$ from the chart (Fig. 2) as in Table A, in which the values are augmented[108] to the extent of 25 per cent. It is admitted that the graph itself is no more than a line drawn free-hand representing a *minimum* estimate, based on the collected results of experience, guided in some degree by theoretical considerations. The author has given his reasons for relying on this rather than on mathematical expressions, which at the best have been devised to fit in with some one or other series of tests, and are less likely to be exact than the unvarnished data on which they are based.[109]

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[106] ξ is of the dimensions L/T^2 (acceleration).

[107] The weigh-bridge or other instrument used in weighing is a *mass comparator*.

[108] For justification, see "The Flying Machine from an Engineering Standpoint," pp. 96 *et seq.*

[109] §8.

In the tables which follow, Table A gives the values of $\mathbf{C}_0$ as a function of $\mathbf{N}_R$. In Table B, column 4, the corresponding values of $\mathbf{N}_R^2\sqrt{\mathbf{C}_0}$ are given. Table D gives values of $\mathbf{n}^{1.5}$; and in Table C are given the values of ρv^2 as related to temperature and altitude.

In the quantitative example (Table B), $\mathbf{n} = 10$. The assumed temperature is 10°C. and pressure 760 mm. The value of ρv^2 is 0.185×10^{-8}. It is convenient to take this in with the constant 1.77, the product being 0.328; the expression in this particular case becomes

$$W = (\mathbf{N}_R^2\sqrt{\mathbf{C}_0} \times 0.328 \times \mathbf{n}^{1.5})/10^8 \text{ (poundals)}$$

the weighbridge *mass* being $W/32.2$ lbs.

TABLE D.

Values of $\mathbf{n}^{1.5}$.

n	$n^{3/2}$	n	$n^{3/2}$	n	$n^{3/2}$
4	8	9	27.0	14	52.3
5	11.2	10	31.6	15	58.1
6	14.7	11	36.5	16	64.0
7	18.5	12	41.6	17	70.0
8	22.6	13	46.8	18	76.4

TABLE C.

Values ρv^2 $(= \mu^2/\rho)$.

Altitude above Sea Level.		(Deg. C.)				
Feet.	Metres.	−10°	0°	10°	20°	30°
		(values ρv^2 multiply by 10^{-8})				
0	0	0.148	0.167	0.185	0.203	0.223
2,000	600	0.159	0.179	0.198	0.218	0.240
6,000	1,800	0.186	0.208	0.230	0.252	0.282
12,000	3,600	0.226	0.255	0.283	0.310	0.342

TABLE A.

Values of $\mathbf{C}_0$ (augmented values).[110]

$\mathbf{N}_R$	$\mathbf{C}_0$	$\mathbf{N}_R$	$\mathbf{C}_0$	$\mathbf{N}_R$	$\mathbf{C}_0$	$\mathbf{N}_R$	$\mathbf{C}_0$	$\mathbf{N}_R$	$\mathbf{C}_0$
10^3	0.0205	10^4	0.0068	10^5	0.0030	10^6	0.0020	10^7	0.00166
× 2	0.0148	× 2	0.0051	× 2	0.0026	× 2	0.00187	× 2	0.00160
3	0.0120	3	0.0041	3	0.0024	3	0.00180	3	0.00156
4	0.0104	4	0.0040	4	0.0023	4	0.00177	4	0.00154
5	0.0092	5	0.0037	5	0.0022	5	0.00174	5	0.00152
6	0.0085	6	0.0035	6	0.00214	6	0.00172	7	0.00151
7	0.0079	7	0.0033	7	0.0021	7	0.00170	10^8	0.00150
8	0.0074	8	0.0032	8	0.00206	8	0.00168	× 3	0.00145
9	0.0070	9	0.0031	9	0.00203	9	0.00167	10^9	0.00141

[110] As in chart (Fig. 2) plus 25 per cent. Compare "The Flying Machine from an Engineering Standpoint," p. 96 *et seq.*

TABLE B.

Example: Expressing W (poundals) and W (mass) lbs. as related to the Reynolds number N_R.
For aerofoil of aspect ratio

$$n = 10$$

$$n^{1.5} + 31.6$$

1	2	3	4	5	6	7	8
N_R	N_R^2	× by	$N_R^2\sqrt{C'_0}$	×.328	×31.6 = W	−32.2 = lbs.	×453.6 = grams
10^3	10^6	10^{-8}	0.00141	0.00046	0.0147	0.000457	0.207
× 2	× 4	,,	0.00487	0.00160	0.0505	0.00157	0.713
× 3	× 9	,,	0.00985	0.00322	0.01018	0.00316	1.440
× 5	× 25	,,	0.02400	0.00788	0.2485	0.00772	3.510
× 7	× 49	,,	0.04350	0.01420	0.4500	0.01400	6.350
10^4	10^8	,,	0.083	0.0272	0.86	0.026	—
× 2	× 4	,,	0.286	0.940	2.96	0.092	—
× 3	× 9	,,	0.596	0.195	6.15	0.192	—
× 5	× 25	,,	1.520	0.500	15.80	0.490	—
× 7	× 49	,,	2.820	0.925	29.20	0.910	—
10^5	—	,,	5.480	1.862	56.8	1.770	—
× 2	× 4	,,	20.40	6.700	211.0	6.560	—
× 3	× 9	,,	44.0	14.43	455.0	14.30	—
× 5	× 25	,,	117.0	38.4	1,190	37.00	—
× 7	× 49	,,	224.0	73.5	2,320	72.00	—
10^6	—	,,	448.0	147.0	4,640	144.00	—

The plotting of the corresponding graph will be found in Figs. 21, 22 and 23.

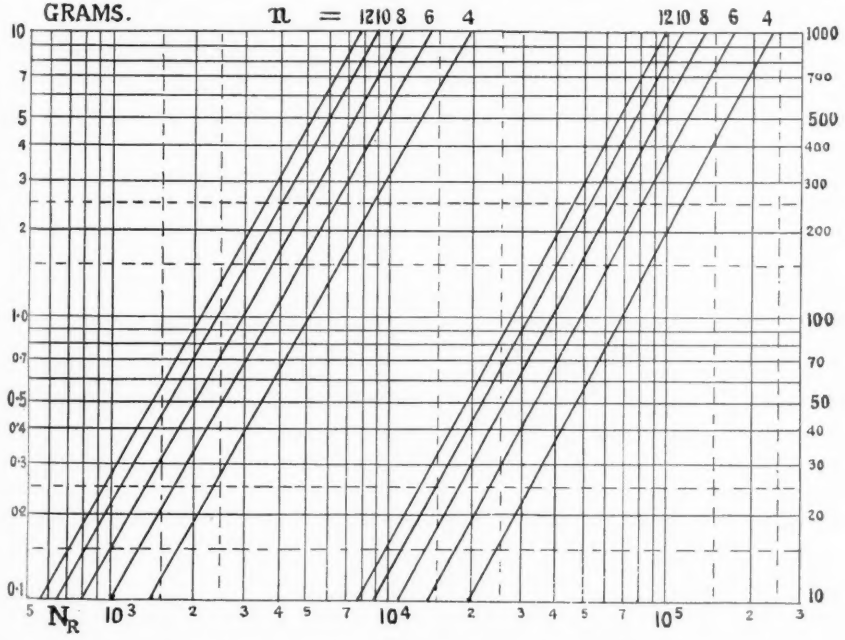

FIG. 21.

Logarithmic chart giving relation between weight, aspect ratio, and Reynolds number, for models 0.1 *to* 1,000 *grams weight.*

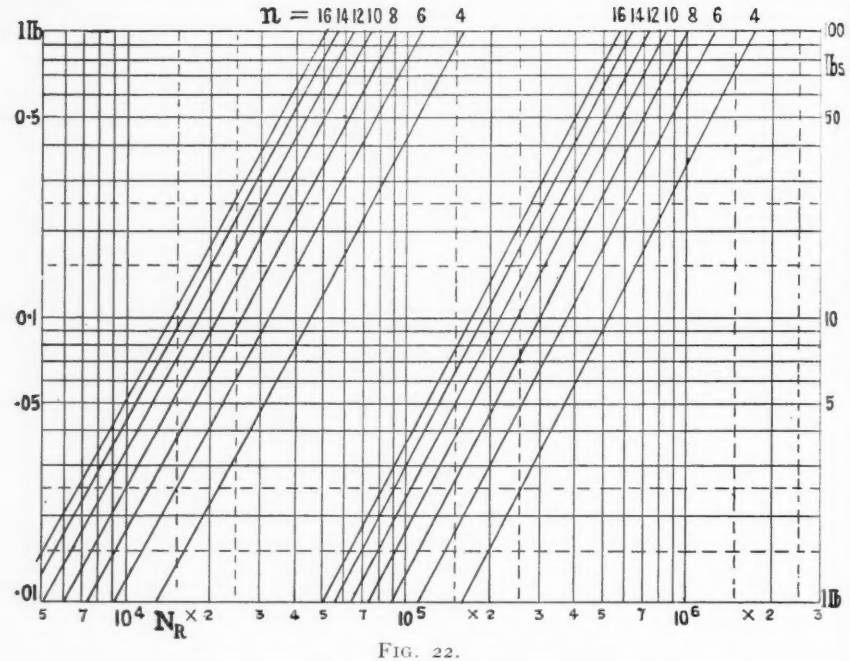

FIG. 22.

Logarithmic chart giving relation between weight, aspect ratio, and Reynolds number, for models 0.01lbs. to 100lbs.

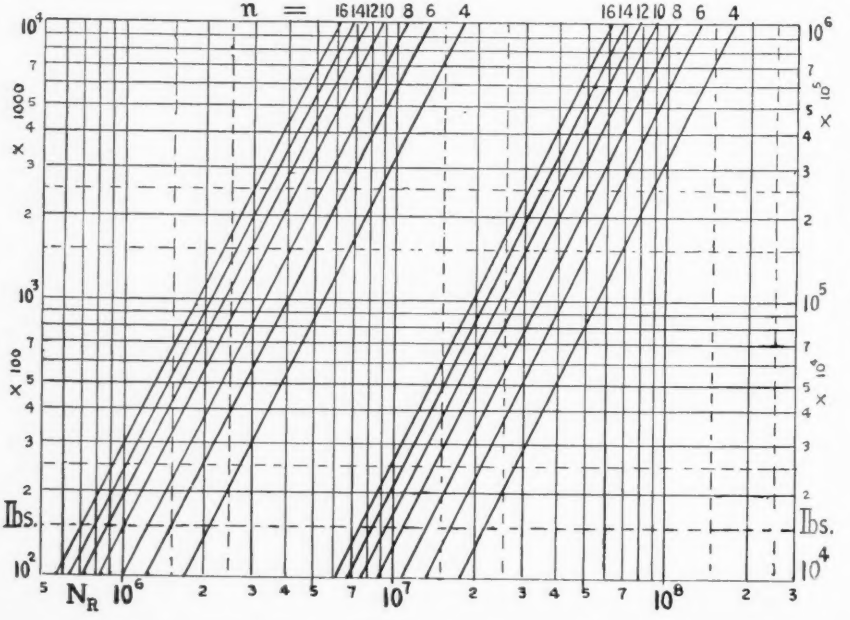

FIG. 23.

Logarithmic chart giving relation between weight, aspect ratio, and Reynolds number, for gliders and full-scale machines, ranging from 100lbs. to 1,000,000lbs.

Appendix III.

The Critical Condition.

The region of instability, or ambiguity, which appears to exist where skin-friction is concerned in the region $N_R = 10^6$ is believed to be consequent upon a critical condition in the régime, similar to, or analogous to, that observed by Osborne Reynolds in the case of the flow of water or other fluid through a pipe or narrow channel. In this latter case it betokens a change from a well-ordered condition of laminar flow, controlled by viscosity, to a condition of turbulence, and the expression connecting resistance with velocity changes from $R \propto V$ to $R \propto V^2$. In the case of skin-friction the index in the case of true laminar flow[111] is 1.5, so that the corresponding change is from $R \propto V^{1.5}$ to $R \propto V^2$; also in the case of skin-friction the change does not take place in all parts of the plane or other body simultaneously. It is usually understood that the leading portion of the surface is subject to laminar flow and that the point of breakaway, *i.e.*, distance from the leading edge, depends upon the value of N_R and upon the smoothness of the surface, also upon the state of turbulence of the air (or water) itself.

It is important to observe that the change of régime as reported does not take place in any definite or orderly manner; the constant C_0 is certainly no longer a single valued function of N_R, and indeed over the range through which the instability extends it may be that the law of dynamic similarity breaks down, or at least its applicability is subject to limitations.[112]

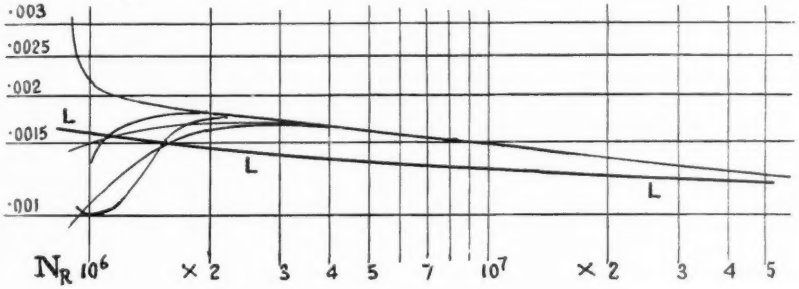

Fig. 24.

Plotting from Mr. G. Baker's paper of 1915, *showing instability in region of* $N_R = 10^6$.

As illustrating this in Fig. 24 is given a diagram showing (somewhat conventionalised) the result of determinations made by Mr. G. Baker in 1915, to whose paper a reference has been given in §9 of the text. This has been investigated more fully by Prof. B. M. Jones,[113] from whose work it would appear that in the case of skin-friction the condition may show itself anywhere between the limits $N_R = 10^5$ and $N_R = 10^7$, Fig. 25 (compare Fig. 4 in the Report cited). It will be seen that this confirms the result previously given by Mr. G. Baker.

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[111] "Aerodynamics," §§33, 34, 35. Also §40 as concerns energy relation.

[112] Without a definite abandonment of the theory. It is always possible, when a quantity y is normally a single valued function of another x, that for some range of values y may be a multi-valued function, and, as a limiting case, the value of y as a function of x (or *vice versa*) may be indeterminate. There is another aspect to be considered; as the value of N_R changes and the system of flow undergoes a modification, a time factor may enter into the problem, so that the relations (in the present case) of C_0 to N_R, even if quite definite in the steady state, may depend, collaterally, on the rate of change, that is upon dN_R/dt. Then there is the possibility of both these influences being simultaneously at work, namely, an unstable or quasi stable condition complicated by the rate of change.

[113] R. & M. 1199, Aeronautical Research Committee, December, 1928.

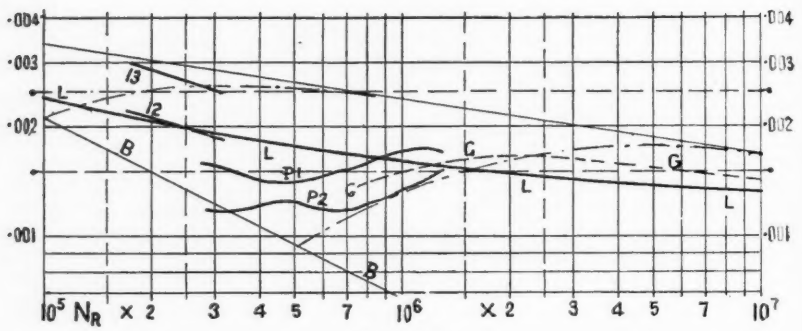


FIG. 25.

Plotting from R. and M. 1199 (Prof. Melvill Jones) showing region of instability and uncertainty extending over range of Reynolds numbers 10^5 to 10^7.

The same phenomenon has also been observed at the same Reynolds numbers in the case of airship models (R. and M. 1199). This might be anticipated from the fact that the resistance of such models is almost entirely a matter of skin-friction. Yet, further, a similar instability in the system of flow has been recorded by Mr. J. R. Pannell of the N.P.L. in a collection of records and investigations concerning the resistance of a sphere.[114]

APPENDIX IV.

HIGH AND LOW REYNOLDS NUMBERS AND HIGH ALTITUDE.

Throughout the paper of which this is an Appendix the value of ρ has been taken as at sea-level, and at 10°C., namely, = 0.078, being the value in British ft./lb./sec. units. The expressions being given in absolute units, no difficulty will be found in substituting any other value appropriate to the occasion, or in applying the same equations when using c.g.s. units.

The author's six propositions and their corollaries, already quoted,[115] apply universally, irrespectively of variations of density and viscosity, provided that the Reynolds number is *high*, such that the law of direct resistance is sensibly $R_f \propto V^2$. Where this is not the case and $R_f \propto V^n$ the needed modification is given in "Aerodynamics," §169, as follows, where x = *direct resistance* $\propto V^n$, and y = *aerodynamic resistance* $\propto 1/V^2$:—

$x \propto (1/y)^{n/2}$; differentiating, $dx/dy = -nx/2y$ and $x+y$ is minimum when $dx = -dy$ or $nx = 2y$ or $x = (2/n)\,y$.

This takes the place of the expression $x = y$ given in Prop. I, and is identical therewith when $n = 2$. The consequences of this for low values of N_R may readily be followed up as affecting the other propositions, but there is no occasion here to consider the matter further; we proceed on the assumption that the Reynolds number is *high*.

In the equation $W = K_L \rho V^2 a$; K_L, for least resistance, is independent of ρ the expression being K_L (opt.) $= 2\sqrt{(\mathbf{C}_o \mathbf{n})}$. And the comparison between high and low altitude does not contemplate any change in the weight sustained W: hence the group $\rho V^2 a$ is constant, and according to the value of ρ as determined by the barometric pressure (mainly affected by altitude) $V^2 a$ must vary, thus,

[114] R. & M. 190 (1916). Here the instability signalising change of system of flow is given as taking place at a value of $2\times(Vl/\nu)$, but what this cryptic expression means the author cannot say.

[115] §21, also see "Aerodynamics," Chapter VII.

$V^2a \propto 1/\rho$. If V be constant then the area a will need to be greater in proportion as the density ρ becomes less. If a be constant then the square of the flight velocity V^2 must be greater in proportion as ρ becomes less. Since a is directly proportional (for given **n**) to the square of the parameter L we may write (1),

$$V^2L^2 \propto 1/\rho \text{ or } V^2L^2/\nu^2 = \mathbf{N}_R{}^2 \propto 1/\rho\nu^2$$

which is in harmony with the expression for W in Appendix II.

The above expression shows that for high altitudes the Reynolds number is inversely proportional to $\sqrt{\rho\nu^2}$; ρ and ν being determined jointly by pressure and temperature, as in Appendix II, Table C, in which values of $\rho\nu^2$ are tabulated. All that really concerns us here is that the reduction in the value of $\mathbf{N}_R$ in passing from a lower to a higher altitude does not have a material effect on the validity of the V^2 law.

Then the six propositions hold, and when flying at high altitude the relation K_D/K_L for least resistance, that is to say, the *constant gradient*, or gliding angle, is the same as at ground level, there is no diminution of resistance to be secured by high altitude flying, so far as concerns the flight organs. The body resistance will naturally be proportional to ρ, that requires no proof, consequently for a given resistance the flight velocity may be increased in the ratio $\sqrt{(1/\rho)}$ the total resistance remaining constant. Alternatively if the flight velocity remain the same, the body resistance will be reduced in the ratio $1/\rho$ which will be clear gain. Some disadvantage lies in the fact that although for given weight the K_D will remain unchanged, the conditions require an increase in aerofoil area, proportional to $1/\rho$, or an increase of span as $\sqrt{(1/\rho)}$ and this will mean an increase of structural weight, involving added drag in like ratio. This subject is dealt with fully in "Aerodynamics," §171.

The author believes that he was the first to point out the economic advantage of flying at high altitude, see Advisory Committee Technical Reports, 1917-18, p. 1182. (Incorrectly quoted in 1934 index volume as p. 1177.)

There are manifest difficulties and drawbacks in extreme high altitude owing to the disabilities under which the motor is called upon to function, but this is outside the scope of the present paper.

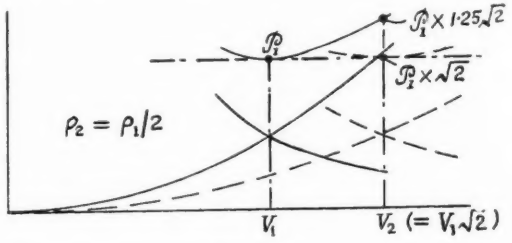


FIG. 26.

Diagram illustrating conditions relating to the economics of flight at altitude.

The position is made clear in Fig. 26, in which by way of example ρ_2 is taken $= \rho_1/2$. The low altitude conditions are indicated by solid lines and the high altitude condition in dotted lines. Taking the h.p. expended at low altitude $(\rho = \rho_1) = \mathcal{P}_1$ the h.p. required at high altitude will be $\mathcal{P}_1 \times \sqrt{2}$, for a velocity $V_2 = V_1 \times \sqrt{2}$. If this higher velocity were to be reached at low altitude $\mathcal{P}$ would be 1.25 as great and this represents the saving of power, namely, 25/125 = 20 per cent. to be realised by flying at an altitude where ρ is half that as subsisting at the lower altitude with which comparison is made.

In §22 mention is made of the apparent inconsistency between the author's Prop. II and Prop. IV. According to the first of these the total resistance or drag is least when the direct resistance of an aeroplane or glider is equal to the aerodynamic resistance. According to the second, Prop. IV, the condition of least resistance requires that the direct resistance of the aerofoil or wings alone shall be equal to the aerodynamic resistance. The explanation is that in Prop. II it is supposed that the aeroplane is a thing *in being*, whereas in Prop. IV the assumption is that the design is to be varied to suit the conditions. The position is this. Let us suppose that a machine, whose gross weight has some definite value, be designed and flown so that its aerofoil direct resistance is equal to the aerodynamic resistance, Fig. 27, Case 1, in accord with Prop. IV. Then let its flight speed be reduced until in accordance with Prop. II its *total* direct resistance is equal to the aerodynamic resistance, Case 2; the resistance will be less than before. Now if we redesign the aerofoil to suit the lower speed of flight so that *its* direct resistance shall be equal to the aerodynamic resistance according to Prop. IV, Fig. 27, Case 3, the total resistance will be less again, and we may repeat this "cycle" as many times as we please, with apparently a continued

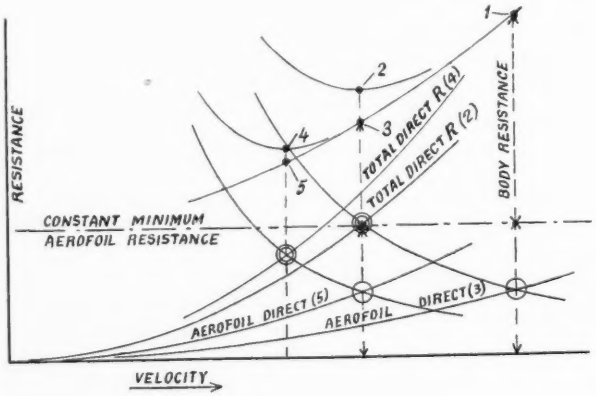


FIG. 27.

Diagram demonstrating agreement between the author's Propositions II and IV.

reduction both of velocity and of resistance. The explanation of this seeming paradox is perfectly simple. According to Prop. V the total aerofoil resistance (presuming best design) is independent of the velocity; this determines the constant gradient to which reference is made in §23. The body resistance is additional to this and varies as V^2 so that it need cause no surprise to find that progressively lowering the velocity results in progressively lowering the total resistance, which approaches more and more nearly to the resistance of the aerofoil alone. The relations under discussion are dealt with more fully in the author's "Aerodynamics," §168.

APPENDIX V.

A simple solution concerning the energy disposed of in the periptery as giving rise to aerodynamic resistance was demonstrated by the author at the conclusion of the reading, illustrated by a model, Fig. 26, where the board A represents the track of the aerofoil in its passage through the air, is supposed to extend indefinitely in both directions, it might be from "Dan to Beersheba," or to bring it nearer home from London to Paris. To make the intention clear an

aeroplane has been indicated painted in black, silhouette. Then, if we conceive the board as rigid and that it have an impulse applied to it at right angles to its surface, it will set up in the air a system of flow as depicted in Fig. 7. We have to conceive the board to which this impulse is due as dissolving away immediately the impulse has been given; this convention is often adopted in the theory of fluid motion as will be immediately recognised by those who have studied any of the standard works on Hydrodynamics, such as Lamb or Basset.

The essential point is that *an aeroplane in its flight from one place to another impresses upon the air the identical system of flow as that to which an impulse as above defined gives rise.* There is around the aerofoil a cyclic system sometimes referred to as the circulation, but this has many of the characteristics of a wave.[116] the energy which it contains is conserved and travels with the aerofoil, the energy expended is that left in the trailing vortices which energy, as stated, may be identified as that due to an impulse applied to a hypothetical rigid plane whose locus is defined by the track of the aerofoil in its flight.

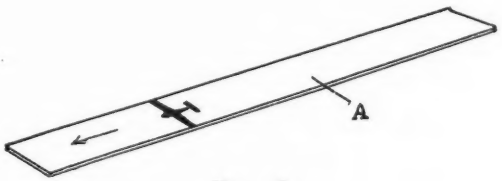


FIG. 28.

DISCUSSION.

The PRESIDENT: They had listened to a master of this art who had dealt with past theory and present practice, and had also given a few predictions as to the future. There ought to be a very interesting discussion. Dr. Lanchester had trailed his coat a little. He had talked of the work of the Aeronautical Research Committee sometimes with approval and sometimes without, but as he had referred to the Reports of the Committee by serial numbers it was a little difficult to know who was the particular victim! As, however, Mr. Relf might be expected to have had something to do with it he would ask him to open the discussion.

Mr. E. F. RELF (*Fellow*): They had all been delighted to listen to this lecture. There was no doubt that Dr. Lanchester was a prophet and when they looked back on the work he did in the early years, with present-day knowledge in mind, it was clear how very much he had done on the question of the theory of flight and sustentation in those early days. He believed it was perfectly true to say that had there been anyone at that time amongst those who were working in the aeronautical field, who was wise enough to follow the lead which Dr. Lanchester gave, they would have arrived much earlier than they did at a great deal of knowledge, particularly as regards frictional resistance and sustentation, and they might even have anticipated most of Prandtl's theory, for Dr. Lanchester undoubtedly gave the basis of it. How Dr. Lanchester arrived at it originally, he did not know.

With regard to the paper, there were one or two points on which he would like to make a few remarks, although it was quite impossible to deal with it adequately in a discussion of this nature. There were too many points in it which merited attention.

In the first place, Dr. Lanchester asked about the identity of his aerodynamic resistance and the induced drag. The answer was surely that the two were identical for elliptic lift distribution over the span. If the wing was loaded in

[116] The author referred to this as a " forced wave " in his Patent Specification 3608 of 1897.

any other way, as, for example, a square ended wing, it was known that the induced drag was greater than that for elliptic loading. In calculating his aerofoil efficiences, Dr. Lanchester had applied his aerodynamic resistance, which was the induced drag for elliptic loading, to aerofoils with square ends, but if he had taken the true induced drag for the rectangular aerofoil, which was about 5 per cent. greater, the agreement with theory would have been closer still, which merely meant saying that the skin resistance of these aerofoils at the Reynolds number in question was very close to that of the flat plate.

The other point he wished to mention was Dr. Lanchester's criterion for minimum resistance when the induced drag and the profile drag were equal. He did not know whether Dr. Lanchester had noticed that that criterion could not be used in designing a modern high speed machine. Looking at Dr. Lanchester's own calculations it would be seen that the aeroplane had a loading of about 50 lbs. per square foot, with the result that the landing speed would be inordinately high, even with flaps, and there would also be difficulty in taking off. The designer was forced to work in an inefficient region with regard to drag, because of the necessity for having a sufficiently low speed for landing and taking off. That was a great pity, because if it were not so, it would be possible to make aeroplanes a great deal more efficient than they were to-day. Therefore, whilst the condition of minimum drag was of great theoretical interest it did not seem to have much practical importance.

With regard to Appendix I, there was a challenge there, and he felt he could not let a challenge go without saying something in reply. Dr. Lanchester was apparently doubtful whether the Reynolds numbers had been correctly calculated in the N.P.L. Report. He thought the reason was that Dr. Lanchester was under a little misapprehension. The pressure and speed given in the tables were only an approximate indication of the test conditions, because the temperature inside the tunnel varied during a test and what was actually done was to keep ρV^2 constant. It was therefore not very accurate to try and deduce the temperature backwards as Dr. Lanchester had done, especially as small errors in V led to big differences in temperature in adopting that method of calculation. Dr. Lanchester could be assured that the Reynolds numbers were correct. Another reason for part of the difference was that he believed Dr. Lanchester had taken the older values for the viscosity of air whereas at Teddington they now used the most recent determinations, which were definitely lower than the older ones.

Dr. LANCHESTER:—But it is not stated whether the figures apply to dry air or humid air.

Mr. RELF: The air in the tunnel was generally just about saturated, but so far as they knew that made no appreciable difference to the viscosity.

In conclusion, Mr. Relf said it had been very delightful to hear a prophet speaking again in modern times.

Dr. G. S. BAKER (National Physical Laboratory): He had really come to the meeting to listen to the aeronautical people and pick up what tips he could from them rather than to speak on Dr. Lanchester's paper, although Dr. Lanchester had been the "draw" which had brought him to the meeting. He had had quite a fellow feeling with Dr. Lanchester when he read the little comment in the paper about ornithologists who did not give scientific data on the subject of bird flight. He had felt that for a long time, and was glad Dr. Lanchester had put it in writing. It was to be hoped that those people who dealt with that subject would take this to heart.

The part of the subject which he knew much better than the application of skin friction to aeronautics was its application to naval architecture. Dr. Lanchester spoke of Froude's law for skin friction. Actually, Froude was too wise to publish such a law with the knowledge that he had. He published a lot of facts and put these facts in the form of certain equations, and William Froude said that as far as he could make out it was possible to extend his data, by a method which he gave, *viz.*, by assuming that the friction of every foot beyond 50ft., was the same

as the friction of the 50th foot. Froude qualified that by saying that no doubt the people who followed him would correct it. It showed the skill of the man, that he was able to put forward something which was so nearly right that they were still using something quite a near approach to it in estimating ship resistance, and in estimating it accurately. Recently, however, in overhauling Froude's data, discrepancies had been found between his published tables and his experimental data, which had led to himself making an enquiry from the Admiralty if Froude's papers could be overhauled. It had been found that William Froude's final analysis had never been published. Mr. Payne, Superintendent at the Haslar tank, has published that data* this year. The velocity index which William Froude gave for models was not the 1.83 mentioned by Dr. Lanchester, but 1.86, and he believed that that represented the considered opinion of William Froude. His son followed him up and gave the law that the resistance varied as the 1.825 power, and that law had been used for 30 or 40 years, but actually it had no experimental backing at all. It merely represented the opinion of R. E. Froude and the facts did not support it.

There was one other point dealing with skin friction, which he wished to mention because what was said in the paper was not quite the fact. It was stated that he (Baker) was the first to observe "instability." When he was Froude's assistant, they used to talk about it, but they did not know what it was due to. His own 1915 paper pointed out the reason for it, but made no claim that he was the first to observe it.

Dr. LANCHESTER: Can you throw any light on it at all?

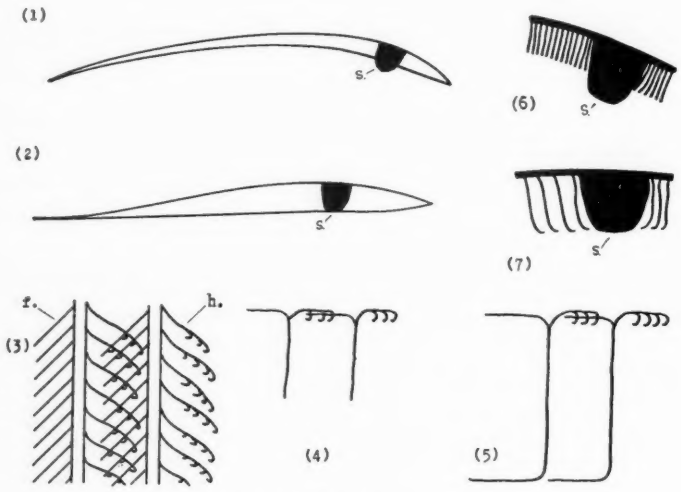
Mr. BAKER: The point at which instability occurred was one which worried all experimenters. He imagined it worried the aeronautical people as much as it did naval architects. Recently, all the Continental tanks and ourselves had been combining in a research to find out what was the Reynolds number below which they should not go, and whether it was possible to obtain results by which a more or less standard value of skin friction could be applied, and the conclusion had been reached that a Reynolds number of 3×10^6 was the lowest which could be used with a comparatively bluff form, and that it was necessary to go to something like 4×10^6 with comparatively knife edge forms. The experiments which had been carried out in the connection had shown some rather curious things. If they had a surface with laminar flow and it was vibrated with a frequency of the order of a musical note, turbulence might be started at once, and the points which various experiments had given to show where that instability began varied tremendously. Jones gave it as from 10^5 to 10^7, *i.e.*, his velocity limits varied 100 times. He thought the reason was simply that the steadiness with which the object on which the measurements were being made had varied, so that turbulence had varied, but if the object was shaken sufficiently fast, sufficient turbulence could be set up in the fluid to get a steady curve, such as Dr. Lanchester had given. A further reason why aeronautical people could stand a lower Reynolds number than was possible in water was that they were working in a fluid in motion, and in which there was naturally a certain amount of turbulence, whereas naval architects moved a model through still water in which the turbulence was very limited.

For the rest of the paper, concluded Mr. Baker, he did not think he had very much to say. He had only received the paper the previous evening, but he had read it through and it seemed to him that Dr. Lanchester was trying to get the aeronautical people to do their work in the same way that naval architects did, *i.e.*, to separate out the skin friction and look at what there was left and work out the efficiency points in that way. He regarded this as the sane way of doing things, and he was surprised the aeronautical people had not done it before.

* Trans. I.N.A. 1936.

The PRESIDENT: It was a great pleasure to hear Mr. Baker taking part in this discussion, because he had done so much on these lines himself. Mr. Baker had spoken in a very modest manner of his own work in this field, but everybody had a very high opinion of it. Incidentally, Mr. Baker had mentioned Dr. Lanchester's reference to ornithologists and it so happened that there was present a member of the Society who was an ornithologist in the person of Commander Graham, whom he would like to say a few words.

Commander GRAHAM: Whilst he did not claim to be an ornithologist, and so hoped to escape the stigma of the lecturer's footnote, he did happen to know a little about birds. The question he wished to ask was whether anybody had ever tried fitting a wing with a very much more rough under-surface than upper-surface and what the effect would be. His reason for asking this was that a striking difference was to be seen between the texture of the under-surface of the important



1. *Section of a typical low-speed feather.*
2. *Section of a typical high-speed feather.*
3. *Enlarged view of parts of two of the barbs that form the web of a feather, seen from above.*
   h. Flexible hooks.
   f. Flexible spines.
4. *Barbs as* (3) *seen in section as found in low-speed feathers.*
5. *Barbs as* (3) *seen in section as found in high-speed feathers.*
6. *Enlarged view of part of* (1) *near the shaft(s).*
7. *Enlarged view of part of* (2) *near the shaft(s).*

NOTE.—*These sketches are not to scale and are drawn from memory from observations in a microscope made in* 1929.

flight feathers in the wings of birds that employed very high speeds of wing stroke as compared with those that employed a slow or normal stroke. These important feathers were those spread-out feathers resembling the fingers of a hand to be seen in the wing-tips of many species of birds. Through their emargination (cutting away at the edges) they could each be considered as separate aerofoils.

In the low speed type, in each feather the shaft or main spar protruded below the webs of the feather and formed a prominent obstruction to the flow of air beneath. Further, the barbs that went to form the web were of such a construction that the boundary layer had to flow across a series of minute ridges. These were the bases of the upright webs of the T section girders, which formed the barbs. This was most prominent in birds like the rook and vulture.

In the high speed type, the vertical webs of the T girders were greatly deepened; deepened in fact to the extent that they had the effect of countersinking the shaft and rendering non-existent that outstanding obstruction to air flow. Further, each of these webs was lapped over at the base in the form of an *L*, with the base of the *L* filling in the gap between each. In this way the undersurface of the feather was rendered as smooth as the upper. This peculiarity was found in partridges, capercaillie, black-cock, and their closer relatives; also in duck and geese, but in very few, if any, other species. It was noteworthy that these birds are among the most heavily loaded types. It might not be too wild a shot to suggest that birds which used a very high speed of flap got certain advantages out of their specially modified feathers, and the first that occurred to one was that strength was provided through the thickness of section to withstand the high stresses of their exceptionally strong and rapid wing strokes. A second advantage was the reduction of skin friction or drag necessitated by the high speed of the wing strokes, as compared with those of other birds such as the rook, the raven, vulture and so on.

As regards the slower speed type, it might be argued that on account of the slow speed of stroke, nature had not found it worth while to waste weight by providing either deep-section feathers or a smooth air flow across the undersurface, but he on the contrary would like to suggest that these slow speed wings derived a definite advantage from the retarding of the lower boundary layer. This advantage might be interpreted as an increase in pressure beneath the wing, or, alternatively as a bending down of the combined air stream in rear of the trailing edge, but whichever way it was regarded the result might be an increase in the resultant force and, on account of the low speed, little or no increase in drag. In conclusion, he wished to point out that there was no readily apparent difference between the texture of the upper-surface of the main flight feathers in the two types of wing. This was uniformly smooth.

Dr. LACHMANN (*Fellow*): He was very grateful indeed for having had the privilege of listening to Dr. Lanchester who had always been a mystic figure to him, and he was very pleased to see him in the flesh. When he was 16 and trying to build a glider, he had read Dr. Lanchester's book but it was all Greek to him, apart from the fact that many expressions in the book were Greek, and he had not had a Greek education. He was perfectly certain, however, that there were still a number of designers and aeronautical engineers who, although they were using the results of Lanchester and of Prandtl's theory, were inclined to believe that vortices, etc., were just mathematical conceptions but they actually materialised at the wing tips if smoke was used. He hoped his colleague Mr. Stafford would tell them how he had actually observed in full scale what Dr. Lanchester called the peripteral area.

Continuing, Dr. Lachmann said he wanted to ask a question in connection with the peripteral area from the point of view of historical interest. When did Dr. Lanchester first express the conception that the virtual mass which was moving downwards was equivalent to a cylinder with the span as diameter? Was it by calculating back from his earlier figures that he found it was so, or had it been expressed long ago? This conception appealed to him as one of the most important physical interpretations of induced drag.

In the part of the paper which dealt with the peripteral area, Dr. Lanchester mentioned that for a rectangular aerofoil the peripteral area would be about 1.27

times as large as for the elliptical plan view, but he wondered how Dr. Lanchester had got the figure for peripteral area given in the fourth line from the bottom of page 86.

Dr. LANCHESTER: He thought there was a little misunderstanding of the paper in this respect. That figure related *not* to the peripteral area but to the area which was subject to a skin friction. It concerned the relation of the area of the aerofoil area to the peripteral area. In the case of the elliptical areofoil this relation was definitely given by the increase of the aspect ratio but that was not so in other cases. In the case of an aerofoil of rectangular plan form area, that factor expressing the area a in terms of A was $1.27/\pi$ the symbol being as defined in §33 of the paper.

Dr. LACHMANN: With regard to the trans-oceanic aeroplane he would like to repeat what Mr. Relf had said. The designer was compelled to work in an inefficient region with regard to induced drag as otherwise the wing loading was such that the machine would not be able to take off unless, of course, one used methods of refuelling in the air when it would be possible to get off with a lighter load and increase the load after taking off, but for long distances those optimum conditions could not be maintained, as the petrol diminished and the wing loading went down.

However, it was a remarkable fact that Dr. Lanchester had predicted this very important law long before any aeroplane ever flew, and also that the minimum rate of descent was obtained at a point where the drag was three times the induced drag. This connection was re-discovered in 1927 by Klemperer and Bienen, after the Prandtl theory had become fully known in Germany.

Dr. LANCHESTER: A great many references had been made to the Prandtl theory but his difficulty was to know exactly what the Prandtl theory was. He wished to give Prandtl the credit for what he did, but the whole of the quantitative results had come out through his own theory and he was still a little in the dark as to what was referred to when mention was made of the Prandtl theory. He had never yet found anyone who could tell him but he was hoping he might do so some day.

Dr. LACHMANN: He was referring to the mathematical edifice which had been built by Prandtl and his school on the conceptions which Dr. Lanchester had first put forward.

Dr. LANCHESTER: His own results had been obtained by simpler means.

Dr. LACHMANN: The expressions used in practice were based on the mathematical formulæ developed by Prandtl.

Dr. LANCHESTER: He had drawn a blank once more.

Mr. ROLLO APPLEYARD: With regard to the remarks of the lecturer and the President concerning birds and aeronautics, that Mr. Hugh Ruttledge had recently shown at the Alpine Club a photograph of a lark nesting upon her eggs at a height presumably at about 20,000 feet. That gave them cause to think of what can be done by adaptation.

Coming to the paper, Mr. Appleyard said it was a welcome contribution to what might be called the state of knowledge relating to aerodynamics. It was an important chapter in the history of the subject, especially valuable because it was Dr. Lanchester's own account of his own achievement in this direction, told in the most modest way, and it would stand as a tribute to him. Attention might well be directed to the manner in which Dr. Lanchester had presented his subject, and to his careful analysis of all the elements of progress. It should be observed that he was a constant advocate of the dimensional method of attack and that

he was always a Newtonian. Dr. Lanchester had made use of the mighty principle of similarity and concerning this he would like to ask him a question, not by way of criticism but because he wanted to know.

The author referred to *geometrical* similarity. Was it not desirable to distinguish between *geometric* similarity and *kinetic* similarity? In *geometric* similarity each line of one machine was equal to the corresponding line of the other, multiplied by the same constant. In *kinetic* similarity there was *geometric* similarity, but in addition, account was taken of the distribution of mass, force and work.

The author's treatment of skin friction was beyond praise. So also was his presentation of the Newtonian principle upon which sustentation ultimately depended. It was to be noted that, whenever possible, the author refrained in his paper from using the word "acceleration," and took the alternative "continuous communication of momentum." Of course, it was the same thing, but here was evidence of the author's modesty; for who, since Newton, had done more to teach us what acceleration was than Dr. Lanchester himself? He invented the accelerometer which was perfected by the President, an instrument which had given them far smoother travel on the railways and in every kind of conveyance. In addition, Dr. Lanchester was the inventor of that wonderful contrivance which they honoured by constantly treading upon it, *i.e.*, the "accelerator" of the motor car. He also gave it its name. It had been used in every means of mechanical transport, on land and sea and in the air.

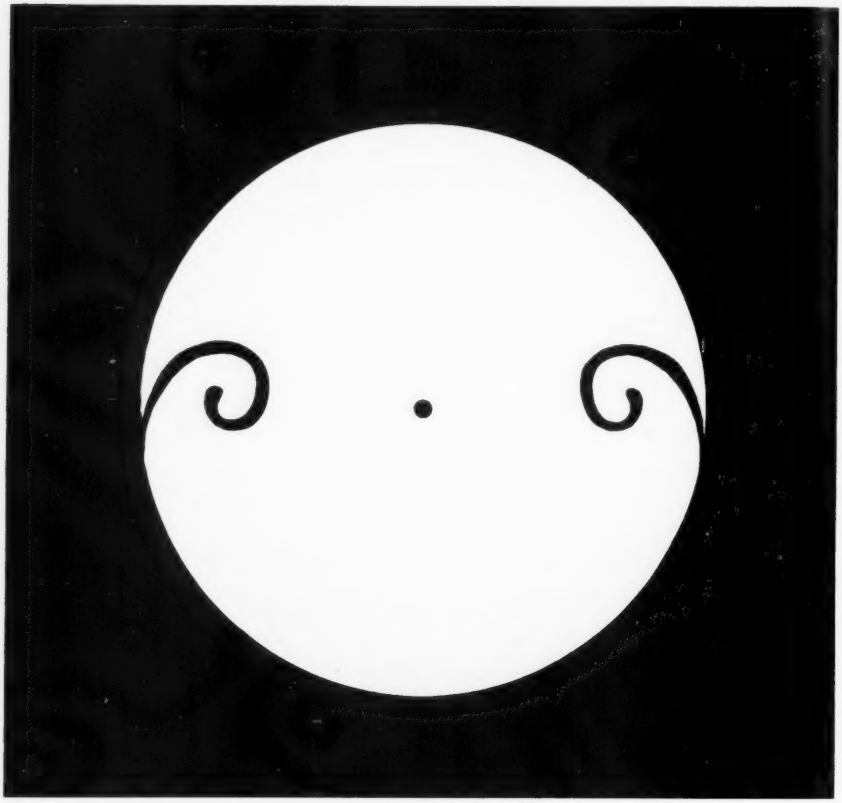
In the paper it was rightly observed that even in the most simple and elementary cases, the component surfaces of a body could not be taken as acting independently without instability. Surely that was one of the most useful and profound sociological generalisations that had proceeded from a physicist and engineer, to ameliorate the lot of man. If politicians would learn that, they would learn much.

With regard to Dr. Lanchester's reference to the work of Newton, it was the opinion of 19th century physicists that although the work of Sir Isaac in hydrodynamics, if it had stood alone, would have immortalised any other worker, compared with the rest of his work particularly that in astronomical mathematics, it was comparatively small. He left a great deal for others to do, but besides that it must be remembered that concerning the dynamics of fluids a great deal had been done before Sir Isaac began his researches upon them: the sequence was from Archimedes to Galileo and Torricelli, Pascal, and then Sir Isaac Newton, Osborne Reynolds and now Dr. Lanchester. It was satisfactory to realise how British physicists and engineers had taken full grasp of that great subject and had combined their efforts with those of investigators on the Continent. Mr. Appleyard concluded by expressing his thanks to the Royal Aeronautical Society for being given the opportunity of being present to hear Dr. Lanchester.

Mr. R. S. STAFFORD: Dr. Lanchester was deserving of thanks for the manner in which he had directed attention to the fundamental aspect of a subject which engineers were rather apt to take for granted.

Dr. Lachmann had referred to a very interesting experience which the speaker had when taking part—as an observer—in a recent test flight. The aircraft, a monoplane, had just climbed through a rather thin cloud layer and on looking back over the tail of the machine he noticed that the machine had apparently "blown" a circular hole in the cloud and at the place where presumably the wing tips might have passed through the cloud, there were trails representative of the wing tip vortices. The sketch illustrates the effect described. The little whirls remained for one or two seconds before they disappeared, leaving what, for want of a better term, he called a peripteral circle. This circle was quite well defined in the cloud and persisted for five or six seconds. It was an interesting experience, and he asked if anyone else had witnessed a similar phenomenon and

whether there was any explanation for the occurrence and persistence of the sharply defined circle.



Prof. S. LEES: He had listened with great interest to Dr. Lanchester's exposition and he had also read his book on "Aerodynamics" of 1907, with the result that quite a lot of difficulties which he had met in this paper had been overcome. The paper covered a vast field but there was only one section of it which he felt competent to offer any opinions about, and that was Part I which dealt with Froude's law—and particularly he would like to say a few words in the presence of Mr. Baker.

At the beginning of the paper, Dr. Lanchester used such terms as "skin friction," "form resistance," and "well designed hull," and he was very careful to point out that Froude's rule would not apply to a coffin or a beer barrel! Later, Dr. Lanchester defined Froude's law and he explained exactly what his application of Froude's law was, *viz.*, that for all well formed airship models of fineness ratio $=5$ and above, Froude's rule shall apply, and it was here, said Prof. Lees that he wished to raise a point.

As he understood the matter (using dimensional theory, which owes a lot to Dr. Lanchester), the resistance R experienced by a body of *any* shape moving at

uniform velocity V in a fluid of density ρ and kinematic viscosity ν, was given by

$$R = \rho V^2 L^2 f(VL/\nu) = \rho V^2 L^2 f(N_R) \quad . \quad . \quad . \quad . \quad (1)$$

where L was taken as the length of the body measured parallel to V, and the function f was (theoretically) settled by the geometrical shape of the body. Factors like gravity g, velocity of sound and roughness of the surface of the body were not supposed to come in.

His difficulty was this. If there was any fundamental difference between "form resistance" and "skin friction," it must show itself in the expression for R, which must then be written

$$R = \rho V^2 L^2 [f_1(N_R) + f_2(N_R)] \quad . \quad . \quad . \quad . \quad (2)$$

where $\rho V^2 L^2 f_1(N_R)$ represents (say) "form resistance" and $\rho V^2 L^2 f_2(N_R)$ represents "skin friction" resistance. Presumably, said Professor Lees, we should take $f_1(N_R)$ as constant $(=A)$ in order to get f_1 essentially different in character from f_2. Thus

$$R = \rho V^2 L^2 [A + f_2(N_R)] \quad . \quad . \quad . \quad . \quad (3)$$

where f_2 approached a constant value for high Reynolds numbers N_R, and at low Reynolds numbers became proportional to $N_R^{-\frac{1}{2}}$. The hydrodynamicians would probably not like the introduction of A, however!

As he saw it, a "well designed hull" would then presumably be one for which the A term was negligible. For such a hull we were left with skin frictional resistance depending on N_R, and giving a resistance at low values of N_R proportional to $(VL)^{3/2}$ as stated by Dr. Lanchester in 1907. Some such ideas as these seemed to be involved in Dr. Lanchester's most interesting curve, Fig. 2, if "form resistance" was to be given a meaning sharply differentiated from skin friction, and was not to be merely a term involving adjustment of the "wetted" area, for purposes of calculation.

Continuing, Professor Lees said there was only one further point he wished to raise. In the lecture, referring to Fig. 2, Dr. Lanchester said, very modestly: "It is admitted that the graph itself is no more than a line drawn freehand representing a *minimum* estimate, based on the collected results of experience, guided in some degree by theoretical considerations." Just before that Dr. Lanchester mentioned "augmented values," where he spoke of the C_o values being increased to the extent of 25 per cent. and he used these "augmented values" in Table A. He would like to know exactly why these values of C_o were increased by 25 per cent. There was a reference given in a footnote, but personally he had not seen that reference.

Dr. BURSTALL: He was a stranger to the aeronautical field, but would like to mention a matter which he believed had a close connection with the subject of the paper, and it was one in which he was very much interested. He referred to the relationship between heat transfer and friction, and he had rather expected that if Dr. Lanchester did not refer to this some of the speakers in the discussion would have done so. He had been very interested in discovering the relationship between heat transfer and friction—a very contentious matter in other circles—and it seemed to him that ultimately the aircraft designer would be faced with the difficulty of removing heat from his engine. He would be forced to do it through the whole surface of the aeroplane. Perhaps that had already been done—he did not know. That being the case, however, it seemed that the indeterminate region on the curve would become exceedingly important because it was well known that a flat plate and a rough surface produced comparatively the same rate of heat transfer, at a very high Reynolds number in certain cases. Similar discrepancies in heat transfer were bound to take place at a region which he believed corresponded to the region on the author's graph, and perhaps Dr. Lanchester in his reply would indicate to what extent he was prepared to prophecy the future of this matter.

Mr. C. C. Walker (*Fellow*, Chief Engineer, de Havilland Aircraft Company) (*communicated*): Some of Dr. Lanchester's conclusions in the course of time have undergone changes in their relative importance. In the early days of flying the power required for sustentation was a large and important fraction of the whole. Now this fraction may be 10 per cent. to 15 per cent. of the b.h.p. developed by the engine or less. It was once said that a vehicle which was, in effect, being perpetually driven up a gradient of about 1 in 6 could never be an economic success, but the way to look at this now is to regard the horizontal transport of the payload in its container as the useful work done, while the presence of sustaining organs which also have to be transported is a small but necessary evil.

Looked at in this way the ideal aeroplane would be all drag and no lift—an infinitely low lift-drag ratio. Unfortunately horizontal transport has to be preceded by the elevation of the load to the operating height, during which process the sustaining organs are all important. The final compromise is between enormous wing span for lifting the greatest possible load, and unobtrusive or rudimentary wings for transporting it. The compromise, when every economic and technical factor is taken into account, goes in the direction of making the sustaining organs as small as can safely be landed with.

The elevation and horizontal transport of the load are not so incompatible as they appear at first sight, because designing for a smaller load to be carried faster on the same power permits of much wing encumbrance being left off. It is not merely a matter of the cube law standing in the way of speed.

The author now says that the peripteral area may be taken as a circle of a diameter equal to the span. This is welcome news for those who have realised the value of this dimension for weight lifting and tried to get as much of it as possible. Has the author checked this assumption (if it is an assumption), against wind tunnel tests on biplanes of different gap/span ratio, and would he suggest that biplane interference would cease when the gap is equal to the span? Max Munk (and possibly others), have published diagrams giving the value of this interference. Do they conform to this conception of the peripteral area? It has sometimes appeared that these curves may not cover all cases in practice.

Dr. Lanchester's achievements in the science of aviation are very remarkable. The writer has often thought they were not fully recognised, and has frequently said so. This struck one very much when his important conceptions (of 20 years before the war?) of aerodynamic and eddy-making resistance were suddenly re-christened and given new parents some years back. The younger generation of aeronautical engineers ought to realise what they owe him. Beginning 40 years ago he visualised the science as a whole and marked out all the important boundaries and limitations. Every problem which was going to limit progress was clearly seen by him and put in its proper place in the whole scheme, whether it was the cost in drag of flight, the importance of the span-wise dimension, the increase of structural weight with size, the transfer of heat by skin friction, the relation of the propeller to the rest of the apparatus; the problems of stability or anything else. His James Forrest and the Institution of Automobile Engineers lectures were masterpieces of clear exposition and comprehensive knowledge.

It may be said that Dr. Lanchester sketched out the whole picture and filled in most of the details. Recent research is mainly filling in and elaborating the details of this same picture. This is at least how it appears to an engineer. The present paper is a presentation of the original fundamental framework with the details examined in the light of to-day's knowledge.

The writer has been a longish time in aeronautical engineering. He has often wished for an opportunity to say how great is the debt that aviation owes to Dr. Lanchester, because he—right at the beginning—closed up all the gaps in the science and thus made it possible to avoid researches and experiments into unfruitful fields.

Reply to Discussion.

Touching the President's introduction in which he paid me some very high compliments, I feel that the suggestion that I am one of the prophets—and indeed a major prophet is a little too flattering. The suggestion came to me almost with as great a shock as though I had found myself canonised and put on the list of saints! I thought that perhaps my conception of the meaning of the word " prophet " was at fault, so I referred to a dictionary, where the definition is given—" One who foretells future events, especially one inspired by God to do so; an inspired teacher of the Divine will." This does remind me of a remark made at a meeting by one of the members of the Advisory Committee for Aeronautics in 1916. When I pointed out that certain of the results reached in the wind channel showed remarkable agreement with the figures given on a theoretical basis in my " Aerodynamics," the member in question made the remark: " We do not believe in your theory," on which I said: " Perhaps you attribute my predictions to Divine inspiration?" He replied: " I would rather that." So that it is clear that the President is not the first to flatter me in this manner!

However unkind it may seem, I must say that I have no wish to claim that my work was the result of Divine inspiration as some appear to think, neither do I wish to be classed with Mother Shipton or old Moore, who amongst the general public are regarded as having " worn the mantle " handed down by the prophets of the Old Testament. I have said that however unkind it may seem I must protest. My work as published in 1907 was a matter of logical deduction, helped but not fully confirmed by experiment. Under the circumstances I did that which I thought to be right, namely, I gave the theoretical results as developed without attempting to bring theory and experiment into line; and, in turn, when dealing with the practical aspect of the subject I made use of figures which could be justified by experience. Surely this work would be more properly described as research than as prophesy?

I must thank the President for his gracious remarks when calling upon Mr. Relf to open the discussion. In reply, I would like to make it clear that I was not looking for a " victim " in my references to the Reports of the Advisory Committee, and its successor the Aeronautical Research Committee. I think, therefore, I was right in referring to these reports by their " R. and M." numbers. A committee is like a limited company of which it has been said: " It has no body to be kicked, no soul to be damned and no conscience to keep it awake at nights," and therefore, I may add, it has no feelings to be considered or " spared." It is unfortunate that occasionally when one questions the wisdom of a committee some individual member seems aggrieved; this is quite unreasonable, there may be dreadful people on any committee, but it is positively indecent to discriminate. A committee is a committee; an organisation, not a mere collection of individuals.

Mr. Relf, in opening the discussion, shows himself at one with our President when he says, " There is no doubt that Dr. Lanchester is a prophet." All I can say, in addition to what I have already said, is that so far as concerns aeronautics I certainly am not a *propheteer*. It is something in these days to be safe from that accusation!

On the question of the identity of aerodynamic resistance and induced drag, as I see it, although the minimum aerodynamic resistance for a given weight sustained is that given by elliptical load grading, such a load grading does not depend upon the plan form of the aerofoil, it may be secured by other plan forms if suitably modelled in other respects. Even the rectangular plan form with profile section constant from end to end does not differ radically from more rational forms in the matter of load grading. This was shown in a comparison given (Fig. 17) in my Wilbur Wright Lecture[117] in 1926 by a figure here repro-

[117] Vol. XXX, No. 190, p. 603.

duced. The quadrant of a circle represents the ordinates of elliptic grading for semi-span and the graphs given are taken from determinations made at the N.P.L.[118] *It is impossible to design an aerofoil with rectangular grading* because this would, in hydrodynamic theory, correspond to a uniform impulse, the resulting motion communicated to the air would be a simple vortex pair, the axes being located at the ends of the hypothetical aerofoil. Such a system *in theory* betokens an infinite expenditure of energy. When, however, the cores of such a vortex pair are constituted by fluid in a state of rotation, the amount of energy becomes finite, and this is what would happen in a real fluid if by any means such a simple vortex pair were to be initiated. Yet, even then the expenditure of power in flight might be enormously greater than would be the case in any actual aerofoil, even though designed by that imaginative genius Heath Robinson. The position was fully appreciated and made clear in my " Aerodynamics," where diagrams were given showing this essential fact that the vortex, as generated in flight, is a compound system or distribution of vortex motion.[119] My own term, *aerodynamic resistance*, is that involved in the generation of vortex motion *whatever* the system of vortices generated may be; the term does not depend upon any particular grading; although the most economical is the elliptical grading. If induced drag has this meaning also, then the two terms are synonymous. According to Mr. Relf this is so, but it seems that he is mistaken in supposing my own term relates *only* to the condition of elliptical load grading; herein lies the crux of the matter.

I consider Mr. Relf's criticism of my criterion of least resistance as set forth in my " Aerodynamics " and restated in the present paper, is quite unjustified. If, in actual flight, a machine is, generally speaking, flown at a speed higher than that of least resistance; the validity of the proposition concerning least resistance is in no way impunged. The condition of least resistance, as stated, is illustrated in Fig. 112 of my " Aerodynamics," reproduced in the present paper, Fig. 5. This figure shows the penalty which attaches to flying at any other velocity greater or less than that of minimum resistance. Although power driven machines are often flown faster than the minimum condition, a sail-plane, unless the upward component of the air current is greater than that necessary, it is desirable and usual to fly at the speed of slowest descent, that is to say, at a speed considerably below the speed of least resistance. This means that the sail-plane is commonly flown under conditions not far removed from the " burble " point. On the other hand, the diagram shows that the speed of flight may be increased by about 25 per cent. with an increase of resistance of only 10 per cent. beyond the minimum. And if for a given distance we are prepared to sacrifice an additional 20 per cent. of fuel (as gauged by the increased flight resistance) the flight speed may be increased approximately in the relation of 3 to 4. The restriction imposed by the size of the aerodrome, that is, the length of the runway in taking-off or alighting, has nothing whatever to do with the question; it is an extraneous condition which results in an artificial limit being placed on the velocity of design, but does not affect the principles involved.

It would be more to the point to urge that the theory of least resistance as given does not take account of the optimum condition when flying with or against the wind. Although, so far as distance run through the air is concerned, the wind makes no difference. When, as is actually the case, our measurements are made relatively to the ground, it is clear that when flying *against* the wind it is economical to fly at a considerably higher speed (through the air) than that betokened by my criterion. On the other hand, when flying *with* the wind the least expenditure of fuel for a given land mileage will be obtained by flying at a lower velocity (relatively to the air). But such considerations require to be

[118] R. & M. 73, 1912/13.
[119] " Aerodynamics," §126, Fig. 83.

founded on the theory of least resistance as set forth and do not invalidate that theory in the slightest degree.

The aeronautical designer will certainly work to better advantage with a clear understanding of the theory of least resistance than by ignoring it, or working on the basis suggested by one of the later speakers that the induced drag is " very small," or " almost negligible."

I think the above entirely answers Mr. Relf's statement that " . . . Therefore, whilst the condition of minimum drag was of great theoretical interest it did not seem to have much practical importance."

When it comes to a question of predicting the maximum range of a machine for transatlantic service, such as I have attempted and which, as Mr. Relf states, would mean about 50lbs. per sq. ft., it must be borne in mind that for such service the future lies in flying under the condition of least resistance, or very near that condition, and to meet this there are clearly two solutions possible, one is that of an aerodrome with a runway something like three miles or more in extent, and the other is to do what I understand is now being attempted, namely, to launch the transatlantic aeroplane from a " mother ship," a larger aeroplane, from a considerable altitude. I am inclined to think that the three or four-mile runway,[120] or five miles if necessary, will be the solution ultimately adopted.

Mr. Relf refers to what he terms a challenge contained in Appendix I of my paper. I think he is under a slight misapprehension as to my intention, but I willingly accept his explanation. I was led to investigate the matter of the Reynolds number in R. and M. 1627, because I wished to be quite sure that the linear dimension, on which this Reynolds number was calculated, was definitely the chord dimension of the aerofoil. Having satisfied myself as to this, my criticism was not that I doubted the accuracy of the figures given, but, as a reader of the report I had been deprived of all opportunity of understanding how the figures had been reached, which is quite another matter. My criticism was a plea that such information as Mr. Relf now gives should have been given in the report itself. If a definite statement had been made that the l used in the calculation of the Reynolds number was the *chord*, I should have had no occasion to raise the point at all. I do think, however, that such information as Mr. Relf has supplied should have been given in the report, and I am not inclined to take anything back as concerns the rider to Appendix I which is a full justification of my criticism.

Dr. G. S. Baker, I note, agrees with my remark touching the ornithologist, I am glad to have his support in this matter. May we hope that the environment produced by this criticism may, on the principle of survival of the fittest, culminate in due course in the evolution of a new species of ornithologist!

Dr. Baker's remarks, when he speaks of the work of William Froude, have served to raise my opinion of that pioneer to a still higher level than previously. I wish to say that I had no knowledge of the recently discovered and published final analysis of Froude's work, to which Dr. Baker refers, and considering the circumstances I do not think that I can be blamed.

One point interests me very greatly, namely, that Froude suggested a velocity index, *not* 1.83 as mentioned by me, but 1.86. This apparently appears in the recently unearthed documents, and Dr. Baker says he believes it to be the considered opinion of William Froude. This is singularly to the point in view of my own remark on page 7, lines 8 *et seq.*, " . . . Many of the leading authorities assign a value of approximately 1.85 to this index as applying to marine conditions, but the author regards this as too low. For the wings of a present-day aeroplane the index is probably in the region of 1.85 to 1.9 and for the body somewhat in excess of that figure; for a modern airship of the rigid type, or an ocean-going liner the index will probably be not less than 1.94." I think

[120] Perhaps aided by a catapult.

it is with great modesty that Dr. Baker states that he was not the first to observe instability, as I had understood to be the case. My personal feeling is that he is entitled to be considered the discoverer. It does not appear that anyone published (or attempted to publish) any observations which would establish the region of instability as a fact prior to Dr. Baker's paper of 1915. Continuing, in answer to an interpolated question, Dr. Baker tells us that this matter is being made the subject of a mass attack by the " continental tanks " and ourselves. He tells us that the conclusion has been reached that a Reynolds number of 3×10^6 is the lowest which could be used with a comparatively " bluff " form, and that it was necessary to go up to something like 4×10^6 with comparatively knife-edge forms. This is substantial justification for my arbitrary definition of a high Reynolds number as being in excess of 2×10^6 (§40).

With regard to Dr. Baker's concluding paragraph, I would like to say this, in defence of the " aeronautical people," that having at one time and another fallen into the trap of separating skin-frictional resistance from " bluffness resistance," as did the late Professor Langley, they have rightly been rather chary in following Dr. Baker's advice—" to separate out the skin friction and look at what there was left." In a sense Dr. Baker is right, but his suggestion must not be taken too literally.

In conclusion I cannot refrain from expressing my feeling of indebtedness to Dr. Baker for his contribution.

Commander Graham made a very interesting contribution to the discussion in informing us as to his researches on the subject of the detail architecture of wing structure. While recognising that his observations may be of considerable value, I do not find any points on which I am able to criticise or amplify what he has himself said. In thanking Commander Graham for his contribution, I will take the liberty of pointing out that it is rather outside the scope of my paper. In my opinion what he has been telling us is worthy of being set down at length with greater detail to be presented to the Society as an independent communication.

When Dr. Lachmann says that he has " read Dr. Lanchester's book, but it was all Greek to him," it is difficult to take him seriously. An excellent and almost exact translation by the late Professor Carl Runge appeared, published by Teubner, within two years of publication in this country. When Dr. Lachmann tells us that he had believed the vortices to be no more than mathematical conceptions, it is quite certain that he did not read my " Aerodynamics " at all, for in Chapter IV devoted to the subject, the vortex system is described in plain language and illustrated by Figs. 64, 68, 70, 71, 72, 73, 74, 75, 78, 79, 83, 84, 85, and 86; *and in the whole chapter there is not so much as a single mathematical expression.* After hearing Dr. Lachmann, I am quite sure that he has not read my " Aerodynamics," and has made no intelligent attempt to do so. Beyond that, in making the statement that he could not understand it, he does himself an injustice. Professor Runge's two boys, Bernardt and Wilhelm, aged 8 and 10 respectively, succeeded in making many mica gliding models from the study of my work, and were able to confirm the fact that for *small* gliders the simple ballasted plane had as good a gliding angle as obtainable from models having a cambered wing section. I cannot refrain from suggesting to Dr. Lachmann that he should take up a copy of my " Aerodynamics " *and read it.* It is commonly the case that when a book is not understood it is due (literally or figuratively) to the fact that the pages have not been cut.

Dr. Lachmann has asked specifically (as a matter of history) when I first " expressed the conception that the virtual mass which was moving downwards was equivalent to a cylinder with the span as diameter." My first publication in which the peripteral area was expressed *in that form* was in a paper read before the Institution of Automobile Engineers in 1915. This, however, was little more than a confirmation in more elegant form supported by a new line of reasoning

of the value previously given in my "Aerodynamics," Table XIII, p. 312 of the English edition, or p. 262 of the German edition. The value then given for an aerofoil of aspect ratio = 6 was $0.78\,S^2$, which is the same thing. In that table a rather higher figure was given for aerofoils of low aspect ratio, and there is some probability that these values are as near the truth as given by the expression $\pi S^2/4$; if the spewing or outflow from the extremities of an aerofoil, as suggested in my reply to Mr. Stafford, is a material factor these higher values may turn out to be justified.[121] The expression on which I founded the theory as presented in 1915 is contained in the concluding paragraph p. 110, "Aerodynamics," English edition, or p. 96 in the German.

It has surprised me to hear that in spite of Runge having translated my work into German in 1909, that the law relating to the least rate of descent should only have become known to Dr. Lachmann something like twenty years later, and then attributed as a *new discovery* to Klemperer and Bienen; would Dr. Lachmann go so far as to say he did not understand this as set out in my book, the book which he is alleged to have read? Would Dr. Lachmann read p. 235 of my "Aerodynamics" (English), or p. 199 in the German edition, and consider how the message could be conveyed in simpler words or by simpler mathematical expression?

With regard to the vortex theory, Dr. Lachmann, it would seem, considers that a mathematical paraphrase is more important than the original discovery *and* quantitative treatment. His position is untenable;[122] the matter has been definitely settled by the award of the Guggenheim Gold Medal in the year 1931. This award conferred by an International Board,[123] whose standing and competence cannot be challenged, says: "Lanchester was the foremost person to propound the now famous theory of flight based on the vortex theory, so brilliantly followed up by Prandtl and others." And later: "That is Lanchester's great achievement, the vortex theory, and upon it his fame chiefly rests."

Replying to Mr. Appleyard, I must first thank him for his very gracious words of appreciation. There is one specific question to which I must reply, namely, the distinction between *geometrical similarity* and *kinetic similarity*. When making use of the Reynolds number the primary condition is strict geometrical similarity, but in connection with the motion of a fluid a difficulty arises—some uncertainty is found to exist.

When writing my "Aerodynamics" I found myself faced with this difficulty, and I made use of the term *homomorphous motion* (§38), because not only the above restriction but other conditions intervene to prevent the assumption being made of perfect kinematic similarity, *i.e.*, geometrical similarity in the motion of the fluid. The conditions I then had in mind are stated in more precise terms in §53 of my recently published work.[124] In order to avoid repetition I must refer Mr. Appleyard to the references cited.

I would like to make a slight correction in what Mr. Appleyard has said as to the word *acceleration* meaning the same thing as *continuous communication of momentum*. Between the two there is a difference of dimensions, namely, in the communication of momentum a mass quantity is introduced; I have no doubt that Mr. Appleyard understands this perfectly. When Mr. Appleyard refers to my being the originator of the accelerometer and also the accelerator used on motor

[121] This is suggested and illustrated in my paper on "The Aerofoil," *i.e.*, note Fig. 14. See also reprint "Two Papers," p. 25.

[122] I think it is quite proper to refer to this theory as the Lanchester-Prandtl Theory. I do not grudge Prandtl his share.

[123] The membership of this Board includes representatives from Canada, England, France, Germany, Holland, Italy and Japan, designated by a leading aeronautical organisation in each country, in addition to eight members of the Trust Corporation controlling the Daniel Guggenheim Fund for the promotion of Aeronautics.

[124] "The Theory of Dimensions and its Application for Engineers." Lanchester, Pub. Crosby Lockwood & Son, London.

vehicles of all kinds, he is carrying us back into the nineties of last century[125] (to-day I note referred to as the " naughty nineties "! Though, having lived then and now, I think it is distinctly a case of the " pot calling the kettle black "!).

With regard to the remainder of Mr. Appleyard's remarks, I am always pleased to see words of recognition of the great example set to us by Sir Isaac Newton. It is my belief that even to-day a careful study of " The Principia " is an education in itself, and a great deal of Newton's work is better studied directly than through those who have attempted to improve upon his teaching by interpretation.

I have been very much interested in the diagram shown by Mr. Stafford, it is not easy to explain why a circular " hole in the clouds," such as described, could be formed by the passage of an aeroplane. The visible indication of the wing-tip vortices is a matter of some interest. I do not think this is a visible manifestation of the vortex motion proper, rather I think it due to a discontinuity formed by the pressure escaping round the wing tips. This, of course, would give rise to a Helmholtz vortex sheet extending beyond the extremities of the aerofoil, and this vortex sheet in turn is, as well known, the seat of origin of trailing vortices.[126]

Space does not permit here of my going further into this, but that this " overflow " or outflow should become visible, I find of very great interest.

Dr. Burstall apparently is not aware of the connection that has been established between skin-frictional resistance and heat dispersal. Although this is rather outside the subject of the paper, I can refer Dr. Burstall to my own contribution to this rather controversial subject which was first presented in the form of a communication to the Advisory Committee for Aeronautics (R. and M. 94, March, 1913), and subsequently in my " James Forrest " lecture of 1914, and again in a paper on cylinder cooling read before the Institution of Automobile Engineers in 1915. The matter was taken up later by the Advisory Committee for Aeronautics in a Memorandum presented by Mr. G. I. Taylor, of the Royal Aircraft Factory (R. and M. 272, May, 1916); Mr. Taylor called attention to the fact that Osborne Reynolds had previously written on the same subject, but no reference was given. Dr. Burstall will find a passage, paragraph (3) of this report, " It has been found by Stanton and Pannell, who have made careful measurements of the cooling in pipes through which air is flowing, that the observed cooling does agree in a remarkable manner with the prediction of Mr. Lanchester." Since that date Mr. Gibson as well as many other workers have gone over the ground again and again and the results have not been very consistent; I do not know what the latest pronouncement is. With the discrepancies signalised in the region of $N_R = 10^6$ concerning frictional drag it is not surprising that discordant results are given by experiments in connection with heat transference. It may be due to this that the various reports on the subject of surface conduction or dissipation of heat have been so much at variance.

I was first faced with this problem when designing the early air-cooled motors which bear my name, in 1895. I then adopted the expedient of soldering gills to an oilman's can containing hot water, which was swung on the end of about three feet of string; the speed of revolutions being taken by a stop-watch and the velocity through the air being recorded. By this procedure, and by taking the temperature of the water before and after the experiment, approximate figures were reached giving the rate of cooling as dependent upon temperature and

[125] Even earlier. My first pendulum accelerometer was made by my own hands in 1889.

[126] This is a phenomenon that should be more readily observed in the case of aerofoils with square or bluff extremities, such as in the case of one of rectangular plan-form, especially when of low aspect ratio. In effect it would represent aerodynamically a slight extension of the span and *perhaps* justify the rather greater peripheral area given for low values of **n** in the table quoted from my " Aerodynamics " than due to the formula $\pi S^2/4$.

velocity. It was when subsequently considering the same problem theoretically that I was able to formulate the theory set forth to which reference has been made. This is an example of how an experiment can be conducted giving useful data at next to no cost. But I fear that it would horrify the Director and Staff of the N.P.L.

In answer to Professor Lees, I would point out that the expression he gives in his equation (1) is only correct for a " body of *any* shape " if the law of geometrical similarity applies and L is a linear parameter. This might be taken as the " length of the body measured parallel to V " or any other linear parameter. The manner in which Professor Lees has expressed it might confuse the reader because in the case of skin friction the condition of geometrical similarity can be relaxed as long as L is taken as the length measured parallel to the direction of motion.

It is agreed that gravity g, the compressibility of the fluid (or as Professor Lees expresses it, the velocity of sound), do not come in, but when reference is made to the roughness of the surface we are " skating on thin ice "; I believe, strictly speaking, the roughness of surface should be subject to the law of similarity, but it is a question to what extent this is the case. However, I will proceed. The difficulty I see is that there is no fundamental distinction by which anyone can say *this is form resistance* and *that is skin friction*. I think the position as far as at present known is this, that the function of the Reynolds number $f(N_R)$ must be considered as relating to the whole body whatever it may be, similarity, of course, being postulated and that when the form of the body approximates to a plane laminar, or may be fairly considered as coming within the description of being a streamline body, then we take the L in the equation as being the length in the direction of flow and relax the condition of geometrical similarity.

I am aware that this does not seem very satisfactory from a mathematician's standpoint, but as Professor Lees is an engineer as well as being a mathematician I do not despair. I think he will appreciate the difficulties of the position.

It is one of the difficulties of the subject, and has always been a difficulty, that in any real case the different kinds of resistance are inseparably associated and it is only when the form resistance or " bluffness " resistance may be ignored that skin friction may be considered separately.

I think Professor Lees " hits the nail on the head " when he says that a " well designed hull " would be one for which the A term in his equation (3) is negligible. We all realise that the position is not altogether satisfactory; the best that can be said for it is that it gives results. It does leave one open to reproach that first one defines a streamline body, or " well designed hull," as one in which there is no resistance other than skin friction, and then one proceeds solemnly to assert that the resistance of such a streamline body or " well designed hull " can be computed on the assumption that its resistance is entirely due to skin friction. Put in this form the position has a distinct touch of humour.

Professor Lees asks what is meant when I refer to " augmented values " when speaking of the constant C_0. Appreciating the fact that our knowledge on the subject is not exact, three reasons may be given for admitting values greater than represented by the graph in Fig. 2, which, as stated, is assumed to represent a minimum. In the first place it is evident that since this graph includes Froude's determinations for tinfoil F_1, and since the graph F_2 relates to a varnished surface we shall be clearly justified in admitting any values between these two graphs as likely to apply to any ordinarily smooth surface. Then, referring to the graph at low Reynolds numbers, it is clear that an increase of 25 per cent. is justified if we assume that Blasius' asymptote is correct; this addition might in fact be as much as 35 per cent. This would also be justified as a mean by the author's two determinations marked L4 and L5. There is one more reason for admitting an augmented value, a reference to this is given in the paper Appendix II, footnote 108.

In the ordinary way it is better to give one reason in a case of this sort than three, but the first two reasons given relate to high and low aspect ratio respectively (different parts of the graph), and the third reason must be considered doubtful in view of Professor Melvill Jones' more recent paper, the upper and lower representations in Fig. 1.

Reply to written communication from Mr. C. C. Walker.

I find myself in a little difficulty in replying to Mr. C. C. Walker. I greatly value his appreciation of my early researches in aeronautics published in my two-volume work in 1907-08, but I find the first paragraphs of his communication rather puzzling, especially when he says (at the conclusion of para. 1 and the opening of para. 2), " . . . while the presence of sustaining organs which also have to be transported is a small but necessary evil."

" Looked at in this way the ideal aeroplane would be all drag and no lift—an infinitely low lift-drag ratio." I assume that from the position Mr. Walker holds and from other evidence of his knowledge of the subject that he has something in the back of his mind which he has not managed to express; to me at least his meaning is not clear. Under the circumstances I think that the best form of reply will be a statement of the case as envisaged in the theory set forth in my " Aerodynamics " and further expounded in the present paper.

Firstly, we confine our attention to the bodiless glider. That this is legitimate is evident from the fact that the body of an aeroplane, whatever its size and form may be, as prescribed by the purpose to which it is to be put, and the conditions of its usage, is subject to a resistance in its motion through the air which, for any given altitude, is not dependent upon anything but its own form and velocity. It may, therefore, be put on one side for subsequent consideration.[127]

The question of auxiliary surface resistance, as due to the rudder, tail plane, etc., are also matter for special consideration.[127] The aerofoil or wing resistance will in the first instance alone be considered.

There is no doubt whatever that Prop. I from " Aerodynamics " is valid, namely, that the total resistance is least when the component aerodynamic and direct resistances are equal, and it is exact as long as the V^2 law of direct resistance applies as is admitted at high Reynolds numbers. It is further accepted to-day that the direct resistance of the aerofoil may be computed on the basis of skin friction.

There is also no doubt whatever that the further proposition (Prop. III) is valid, namely, that the total resistance, under the condition of best design, is independent of the velocity of flight. That is to say, if a number of gliders be designed to sustain a given weight to comply with the condition of least resistance, the total aerofoil resistance will in every case be the same. Identical aspect ratio and plan form are, of course, assumed.[128] This must be true if the tables and plottings given in section IV of the paper mean anything. The value of K_D for any given value of K_L is the same whatever be the velocity.[128] And conversely these diagrams apply irrespectively of the value of W the load sustained.

So that if we are dealing with a glider (at high values of N_R) the condition that the most economic speed of flight is when the two kinds of resistance are equal is absolutely true.

What Mr. Walker means when he says, " The ideal aeroplane would be all drag and no lift," I cannot conceive; if he did not repeat the same thing by saying, " An infinitely low lift/drag ratio," I should have thought that it was a case of the accidental transposition of words, for if on the contrary an aeroplane could be designed all lift and no drag *that* would be an ideal machine, such an

[127] Congrave text of paper, §38.
[128] They are thus assumed to differ only in size.

achievement would only be possible if the air were a perfect fluid and the extremities of the aerofoil were masked by parallel vertical walls.[129] In practice the condition which comes nearest to this is found in the glider, then it is a component of gravity which neutralises the drag, and in still air provides the energy; when riding on an up-current it is, of course, the wind (up-current or upward component) which provides the energy, but the zero net drag is still due to the real drag being neutralised by a component of gravity. Surely that is the ideal condition and not the contrary. And the corollary is naturally that the lower the drag in terms of lift the better, not the contrary as Mr. Walker has stated.

On the next point raised. In my present paper, as will be appreciated by those who have read it through, I have confined myself to the monoplane, and it is this to which the law, peripteral area = $\pi S^2/4$, applies. In my paper of 1915 (Inst. A.E.),[130] Appendix VI, the case of the biplane is considered at some length, the discussion being based both on theory and on wind channel figures. In a diagram (Fig. 27) it is suggested that the effective peripteral area may be represented as that of a circle whose diameter = span, *plus* a rectangle whose area is = *span* × *gap*, this rule only applying in the case of gaps about = chord. Departures from this condition are discussed and a diagram (Fig. 28) is given in which a graph appears of more general application. I think Mr. Walker would find it profitable to make a study of the paper cited.

I am inclined to give a word of warning on the subject of the application of mathematical elaboration when discussing real problems in aerodynamics.[131] Although the *arithmetic* concerning the economics of flight is more precise as depending upon the first principles and less upon empirical data than is the case in other modes of locomotion, it is possible to overweight the subject with elaborate mathematics. It is rare that anything more than the simplest algebraic expressions, scarcely worth dignifying with the name of mathematics, serve any useful purpose. In this connection the most elaborate investigation I have found necessary is that relating to the differentiation of an expression resulting in two simultaneous equations, in order to obtain an expression giving the condition of least resistance, taking account of the weight of the aerofoil. This will be found in my "Aerodynamics," § 171, at the conclusion of Chapter VII.

In conclusion, I am glad to note that Mr. Walker is *not* one of those who "could not understand" my various published works, it is evident that he is one of the few who has taken the trouble "to read, mark, learn, and inwardly digest."

(In answer to a question by Professor S. Lees.)

Derivation of $R_d \propto 1/V^2$.

By eq. (1) $r = W/(m/s)$. Eq. (2) power $= (m/s)\, v^2/2$

where $(m/s) = AV\rho$.

$$\therefore R_d = (m/s)\, v^2/2V = (m/s)\, W^2/(m/s)^2\, 2V = W^2/2V^2A\rho.$$

(W is given = const. A and ρ are constant.)

$$\therefore R_d \propto 1/V^2.$$

The PRESIDENT: He wished to express to Dr. Lanchester the most cordial thanks of the meeting for having given such an excellent lecture and at the same time to express the deep respect and, might he add, affection in which Dr. Lanchester was held by the entire Royal Aeronautical Society.

The vote of thanks was carried with hearty enthusiasm.

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[129] This supposition is precisely equivalent to regarding the aerofoil of infinite span carrying a correspondingly infinite load, but gives a great degree of realism. In both connections the motion engendered is two-dimensional.

[130] Vol. IX, pp. 223, et seq.

[131] It is no use weighing "sugar-plums" on a chemical balance, or employing a micrometer to gauge acorns.

SOME RESULTS OBTAINED ON THE CATHODE RAY ENGINE INDICATOR.

By E. M. Dodds.

We have published elsewhere* a considerable amount of work on the development of the cathode ray engine indicator and, while most of the pressure elements and circuits which have been developed are perfectly satisfactory on normal petrol and Diesel engines, it has been impossible up to the present time to obtain a really satisfactory pressure-time card on the high duty boosted aircraft engine, the main difficulty being due to the super position of mechanical vibration on the pressure-time diagram. A satisfactory knock indicator has, however, been produced and a few of the results are here discussed, in the hope that they may be of general interest.

The indicator employs a pressure element of the capacity type, consisting only of steel and mica, which need not even be water-cooled, as the diaphragm is

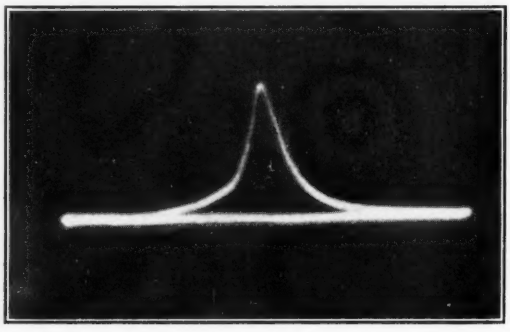

Fig. 1.

Pressure time diagram—no knock.

supported against engine pressures. This element is very robust from the mechanical point of view and is excellent thermally. Diagrams representing either pressure against time or rate of change of pressure against time are obtained directly from the element by means of a straightforward amplifier. In this connection, it should be pointed out that both the pressure element circuit and amplifier must possess a flat frequency response to at least 50,000 cycles per second if accurate oscillograms are to be obtained under conditions of detonation. The necessity for such an overall frequency response has not previously been appreciated in commercial instruments.

In Figs. 1 to 11, are shown photographs obtained by this instrument on a Series 30 engine at 8-1 compression ratio, running at 960 r.p.m., the length of each corresponding to 360° crank rotation, each revolution starting from the left-hand end. Normal petrol and Diesel engines give results equally free from superimposed mechanical vibrations. These diagrams, with the exception of Figs. 1 and 3 are typical of the results to be expected on aircraft engines. It is probable

* See References at end of paper.

that within the next two or three years pressure-time cards of high accuracy and steadiness may also be obtained on an aircraft engine.

Fig. 1 shows a pressure-time diagram on the Series 30 engine in which no detonation is present, while Fig. 6 represents the corresponding diagram of rate of change of pressure against time. Fig. 2 is identical with Fig. 6, except that the Y axis amplification has been very considerably reduced. This is achieved electrically and is valuable in studying different detonation intensities, as will be explained at a later stage.

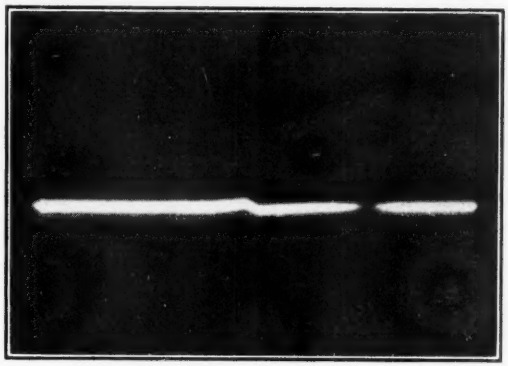

FIG. 2.

Rate of change of pressure against time—vertical amplification reduced. Corresponding to Fig. 1.

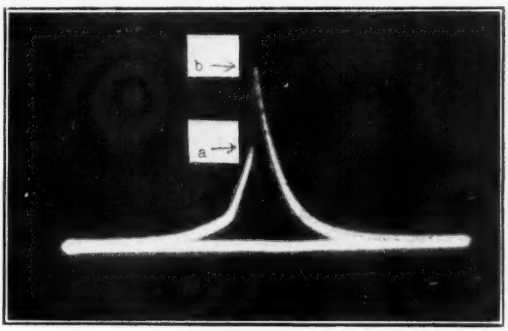

FIG. 3.

Pressure time diagram—with knock.

Fig. 3 represents a pressure-time diagram under the same engine conditions as those obtaining for Fig. 1, with the exception that a knocking fuel has been substituted for one free from knock. The extent of the detonation pressure rise is shown from *a* to *b* in the illustration.

Fig. 4 shows the rate of change of pressure diagram corresponding to Fig. 3. It must be clearly understood that Figs. 2 and 4 are obtained with the same Y axis amplification. The important point to observe is that although detonation is shown up reasonably clearly by Fig. 3, the rate of change diagram—Fig. 4—is markedly more sensitive in assessing the degree of detonation.

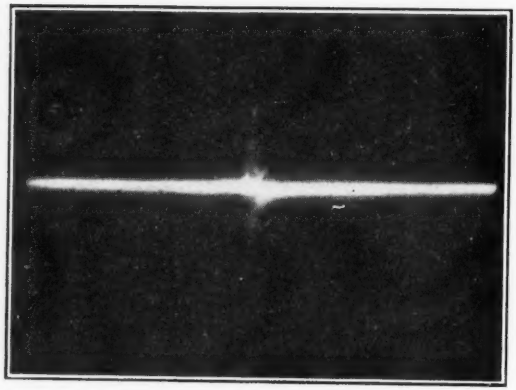

FIG. 4.

Rate of change of pressure against time, same amplification as Fig. 2. Corresponding to Fig. 3.

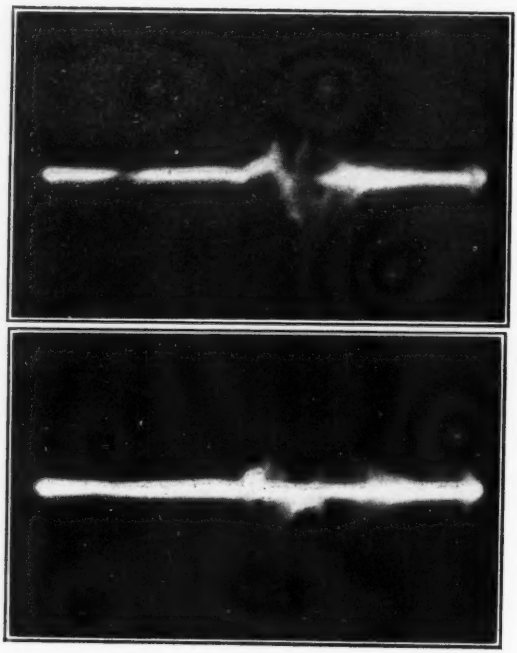

FIG. 5.

One curious phenomenon which we have discovered by the use of our new indicating apparatus, is the possibility of making benzole detonate well down the power stroke, when both the temperature and pressure of the gases have dropped to perhaps one quarter of their maximum value. The engine conditions which foster such detonation are full throttle, retarded ignition, and a local hot spot in the combustion chamber.

Fig. 5 is a typical rate of change diagram under these conditions, the corresponding pressure-time diagram giving a ripple on the expansion curve which is

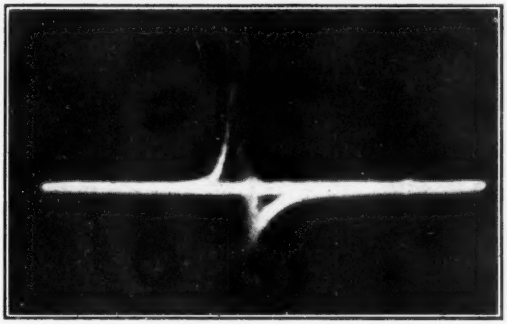

FIG. 6.

Rate of change of pressure against time—no knock. Corresponding to Fig. 1.

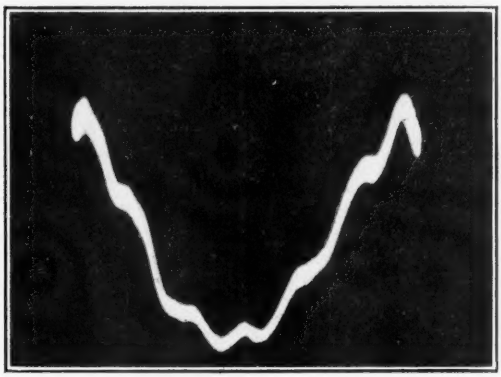

FIG. 7.

Fly wheel motion in its own plane. Throttle shut—ignition switched off.

barely visible. Admittedly, these conditions of operation are not quite normal but, on the other hand, other types of cylinder might possibly give similar results at more normal settings. This type of knock sounds like a valve squeaking in its guide. It is possible that something of this kind may occur on an aircraft engine using fuel containing a high percentage of aromatics, the detonation so produced being very much less destructive than normal, since it occurs at much

lower temperatures and pressures than those experienced on fuels possessing only a small proportion of aromatics.

Since the instrument employs capacity change to achieve these results, very wide possibilities are opened up in the direction of obtaining oscillograms of either motion or velocity of moving parts by simply arranging an insulated plate at a short distance from the moving part. One such application is shown in Figs. 7 and 8, and 9, in which the insulated plate has been arranged parallel to,

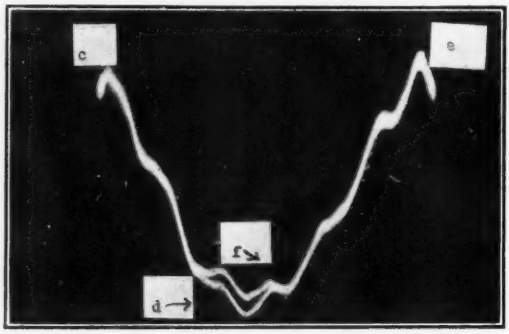

FIG. 8.

Fly wheel motion in its own plane.
Throttle open—ignition switched off.

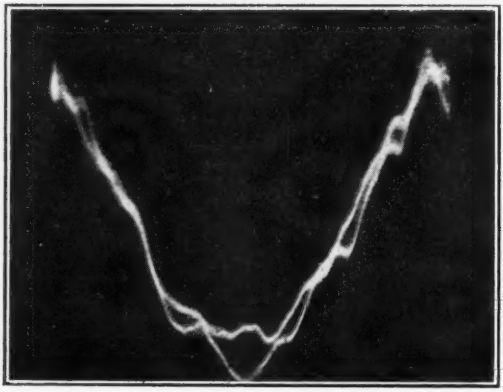

FIG. 9.

Fly wheel motion in its own plane.
Throttle open—ignition switched on.

and at a short distance from, the face of the engine fly-wheel. Fig. 7 is the oscillogram corresponding to shut throttle and represents the degree to which the fly-wheel is running out of truth. The oscillations of small amplitude which are superimposed, represent a combination of surface irregularity and end float of the crankshaft. Fig. 8 shows what happens when the throttle is opened with the ignition switched off. Successive revolutions are now different, in that the compression of the charge now bends the crankshaft slightly, which tips the fly-

wheel and thereby gives rise to the curve *c-d-e* as compared with the curve *c-f-e* on the exhaust and intake revolution. Fig. 9 shows the extent to which this tipping of the fly-wheel is augmented when the ignition is switched on and combustion pressures occur above the piston. Knocking combustion, as distinct from quiet combustion, is easily distinguished on diagrams of this nature.

Another simple application involving change of capacity lies in the direction of showing the extent and period of opening of the valves in the cylinder head. This is achieved by arranging an insulated plate near any convenient moving part on the end of the valve stem or rocker. Provided no appreciable valve overlap is present it is obviously possible to arrange a common pair of such insulated plates, one near the inlet and the other near the exhaust valve, so as to give a diagram representing the opening of both valves. A diagram showing this particular application is shown in Fig. 10, while Fig. 11 represents the motion of the inlet valve only. This type of diagram shows up valve bounce the moment it occurs. Valve spring surge is investigated in a similar manner, by indicating the motion of the lower coils of the spring. If surge is absent, a figure similar to Fig. 11 is obtained but, naturally, the amplitude is smaller. If surge is present this diagram of valve lift will oscillate along the time axis.

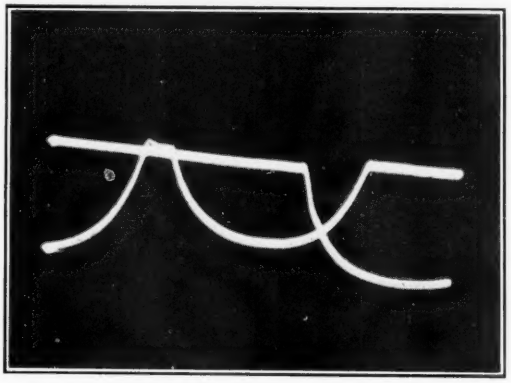

FIG. 10.

Superimposed diagrams of inlet and exhaust valve motions.

Enough has been said to show the extreme versatility of this indicator, since a large number of problems can be tackled with it by arranging comparatively simple attachments to the engine.

C.F.R./AERO ENGINE CORRELATION.

In view of the difficulties of correlation between the C.F.R. motor method and aircraft engines, it would seem that any effort in the direction of trying to obtain an average rating on the C.F.R. is of little value, by virtue of the extremely large discrepancies which exist between the ratings given by aero engines themselves. A more promising line of investigation might be to develop a separate C.F.R. technique to correlate with each aero engine under each set of normal running conditions. Thus it might be possible to choose C.F.R. conditions to correlate with liquid cooled engines at cruising power, another set of conditions to reproduce fuel tests at take-off power, and similarly for air-cooled engines. The duplication of C.F.R. tests required might not, after investigation, be as complicated as would at first appear and would be more convenient and less

expensive than conducting frequent fuel tests on individual single cylinder and complete aero engines. Many of the possible variables on the C.F.R. engine are easily adjusted, *e.g.*, jacket temperature, intake temperature, ignition timing, throttle opening and intensity of detonation.

Perhaps the last is the most important of these. It does not seem logical to rate fuels under the present standard knock, which is of comparatively large intensity, when fuels are rated on aircraft engines at incipient or slight detonation. This leads us to the question of measuring incipient knock on the C.F.R. For this purpose we have found the cathode ray indicator to give promising results as a knockmeter.

Indicating Detonation Without Engine Attachments.

In addition to satisfactorily indicating knock in an aircraft cylinder, into which a pressure element is screwed, we also succeeded some time ago in indicating knock on the Bristol aero engine by simply forcing the insulated lead which normally connects with the pressure element, between the upper cooling fins of the cylinder. Excellent results have also been obtained on liquid-cooled engines

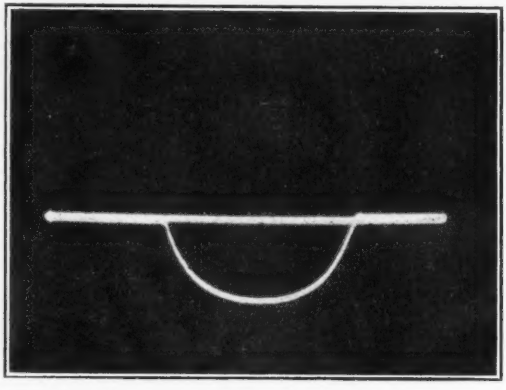

Fig. 11.

Diagram of inlet valve motion.

by holding an insulated plate on a sheet of mica over a suitable part of the cylinder head casting. For this work a time base is not really necessary, so that our new knockmeter can be used on an aircraft engine without the necessity for having anything, whatsoever, connected to the engine. The advantages of such a method are obvious. All that is necessary in the case of the main engine, for example, is to obtain detonation oscillograms from each cylinder in turn, so as to determine which is subject to the heaviest knock, the lead then being left between the fins of that cylinder for subsequent fuel tests. Calibration would be performed in the ordinary course of events on the similar single cylinder test unit, and the results on the main engine could then be evaluated.

It is hoped in the near future to produce a simplified, compact, and light-weight version of this instrument, involving either a suitable meter or, preferably, a miniature cathode ray tube, which could be fitted in the cockpit of a machine, enabling the pilot to detect detonation long before it becomes audible to him and, therefore, destructive in character. A simple instrument of this character has also a number of possibilities for use as a C.F.R. knockmeter under conditions of either standard or incipient knock intensity, without the necessity for having a pressure element in the cylinder head.

A small cathode ray tube would appear to be preferable to a meter because of the inconsistency of the detonation which occurs in any normal cylinder. For example, with light detonation there are generally a larger number of cycles in which detonation does not occur than in which it does occur, even to the extent of, perhaps, ten or twenty silent combustions to one knocking combustion. Under conditions such as these, any circuit involving inertia, either electrical or mechanical, as when a meter is used, is not likely to show up to advantage against the cathode ray tube on which each individual cycle is seen.

We should like to place on record our appreciation of the valuable help given us by Messrs. Kodak, Ltd., in obtaining the photographs reproduced.

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"Cathode-Ray Oscillograph Engine Indicator," "Engineering," Vol. 140, Aug. 23, 1935, pp. 183-186.

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"Development and Application of the Cathode-Ray Engine Indicator," by E. M. Dodds, S.A.E. Journal, December, 1936.

ABSTRACTS AND NOTICES

FROM THE

SCIENTIFIC AND TECHNICAL PRESS

Issued by the

DIRECTORATES OF SCIENTIFIC RESEARCH AND TECHNICAL DEVELOPMENT,
AIR MINISTRY.

(Prepared by R.T.P.)

No. 40. DECEMBER, 1936.

AERODYNAMICS AND HYDRODYNAMICS.

Correction of Downwash in Wind Tunnels of Circular and Elliptic Sections. (I. Lotz, N.A.C.A. Tech. Memo., No. 801, translated from L.F.F., Vol. 12, No. 8, 25/12/35.) (Available as Translation No. 350.) (574/2908 Germany.)

Up to the present the tunnel interference effect has been determined at the centre of pressure of the middle wing section. The downwash velocity at this point can be simply determined and is equal to half the velocity with infinite flow. The latter can be represented as a two-dimensional potential flow with a system of images of the trailing vortices being set up at the boundary. In the open tunnel, the vortex images have the same sign as the original vortex; in the closed tunnel they have opposite sign. So far the value of the downwash velocities from the wing outwards to infinity were not known accurately. A first approximation was obtained by Glauert for the downwash at the tail surface in a rectangular tunnel. The present paper gives the exact solution for the induced velocities for circular and elliptic jets.

Calculated and Measured Pressure Distributions Over the Midspan Section of the N.A.C.A. 4412 Airfoil. (R. M. Pinkerton, N.A.C.A. Report No. 563, 1936.) (2953 U.S.A.)

Pressures were simultaneously measured in the variable-density tunnel at 54 orifices distributed over the midspan section of a 5- by 30-inch rectangular model of the N.A.C.A. 4412 airfoil at 17 angles of attack ranging from $-20°$ to $30°$ at a Reynolds Number of approximately 3,000,000. Accurate data were thus obtained for studying the deviations of the results of potential flow theory from measured results. The results of the analysis and a discussion of the experimental technique are presented. It is shown that theoretical calculations made either at the effective angle of attack or at a given actual lift do not accurately describe the observed pressure distribution over an airfoil section. A modified theoretical calculation is developed which agrees reasonably well with the measured results. The circulation is evaluated by means of the experimentally obtained lift at the effective angle of attack; *i.e.*, the angle which the chord of the model makes with the direction of the flow in the region of the section under consideration. In

the course of the computations the shape parameter is modified, thus leading to a modified or an effective profile shape that differs slightly from the specified shape.

Electrical Stream Potential during Turbulent Flow. (H. Reichardt, Zeitschrift fur Physikalische Chemie, Vol. 174, No. 1, Sept., 1935, pp. 15-21.) (3012 Germany.)

Measurements were carried out on a capillary tube 0.082 cm. diameter and 52.84 cm. long, using distilled water. The electric stream potential E was measured using normal KCl electrodes. It was found that E was directly proportional to Dp, the pressure drop, irrespective of whether the flow was laminar or turbulent. From this it appears that the flow in the electrical double layer is always laminar, the dimensions of this layer being small compared with that of the hydrodynamic boundary layer. The author had hoped to use the electrokinetic method for a direct determination of shear at the boundary. It was, however, found impossible to obtain a surface sufficiently homogeneous to give consistent electrical properties of the boundary.

The Forces and Moments Acting on Parts of the XN2Y-1 Airplane during Spins. (N. F. Scudder, N.A.C.A. Report No. 559, 1936.) (3144 U.S.A.)

The magnitudes of the yawing moments produced by various parts of an airplane during spins have previously been found to be of major importance in determining the nature of the spin. Discrepancies in resultant yawing moments determined from model and full-scale tests, however, have indicated the probable importance of scale effect on the model. In order to obtain data for a more detailed comparison between full-scale and model results than has hitherto been possible, flight tests were made to determine the yawing moments contributed by various parts of an airplane in spins. A direct comparison between wind-tunnel and flight results will be possible as soon as the tests of a model of this airplane have been completed on the N.A.C.A. spinning balance. The pressure distribution tests incidentally demonstrated the favourable interference produced by the horizontal tail surfaces on the part of the vertical surfaces below them and the unfavourable interference produced on the part above them.

Turbulence Factors of N.A.C.A. Wind Tunnels as Determined by Sphere Tests. (R. C. Platt, N.A.C.A. Report No. 558, 1936.) (3163 U.S.A.)

Results of drag and pressure tests of spheres having diameters of 2, 4, 6, 8, 10 and 12 inches in eight N.A.C.A. wind tunnels, in the air ahead of the carriage in the N.A.C.A. tank, and beneath an autogyro in flight are presented in this report. Two methods of testing were employed, one involving measurements of sphere drag and the other measurements of the pressure difference between the front stagnation point and the rear portion of the sphere. Satisfactory correlation between the two methods was obtained experimentally, as set forth in an appendix to the report. When the Reynolds Number of a model tested in a wind tunnel is multiplied by the turbulence factor for that tunnel, the resulting value is an " effective " Reynolds number. When this method is used to obtain the scale-effect variation of maximum lift coefficient and drag coefficient at zero lift of certain well known aerofoils, data obtained in various wind tunnels under a wide variety of turbulent conditions are brought into satisfactory agreement.

A General Tank Test of a Model of the Hull of the British Singapore IIC Flying Boat. (J. R. Dawson and S. Truscott, N.A.C.A. Tech. Note No. 580, Sept., 1936.) (3210 U.S.A.)

A general test was made in the N.A.C.A. tank of a 1/12- size model of the hull of the British Singapore IIC flying boat loaned by the British Air Ministry. The results are given in charts and are compared with the results of tests of a

model of an American flying boat hull, the Sikorsky S-40. The Singapore hull has a greater hump resistance but a much lower high speed resistance than the S-40. The results of the tests are also compared with the results from tests of the same model which were made in the R.A.E. tank and the agreement is found to be close. It may be concluded that the results obtained in the smaller British tanks have not been affected by proximity of the walls and the bottom.

The Surface Tension of a Moving Mercury Sheet. (H. O. Puls, Phil. Mag., Nov., 1936, pp. 970-982.) (3359 Great Britain.)

Bond's method of using the impact of two liquid jets for the determination of surface tensions is applied to mercury. The mercury is circulated and a device for the continuous measurement of the rate of flow of the liquid is described. A method for determining the momentum of the jet is developed, from which the radius of the jet is deduced. The value of the surface tension of mercury in contact with air at 20° C is given as $475{\cdot}5 \pm 2$ dynes/cm. A survey of the results of other workers is added.

Analysis and Model Tests of Autogiro Jump Take-off. (J. B. Wheatley and C. Biolletti, N.A.C.A. Tech. Note No. 582, Oct., 1936.) (3432 U.S.A.)

An analysis is made of the autogyro jump take-off, in which the kinetic energy of the rotor turning at excess speed is used to effect a vertical take-off. By the use of suitable approximations, the differential equation of motion of the rotor during this manœuvre is reduced to a form that can be solved. Only the vertical jump was studied; the effect of a forward motion during the jump is discussed briefly. The results of model tests of the jump take-off have been incorporated in the paper and used to establish the relative accuracy of the results predicted from the analysis. Good agreement between calculation and experiment was obtained by making justifiable assumptions.

The Forces on a Solid Body in a Stream of Viscous Fluid. (T. E. Garstang, Phil. Trans. Roy. Soc., Vol. 236, No. 759, 20/10/36.) (3444 Great Britain.)

Previous work of Filson and Goldstein is extended and the work facilitated by the introduction of certain associated Legendre functions. The drag is found to be associated with one of the irrotational solutions whilst the lifting force is connected with the circulation round the diffused vortices at infinity.

The Distribution of Velocity and Temperature Behind a Grid in Air in Turbulent Motion. (R. G. Olsson, Z.A.M.M., Vol. 16, No. 5, Oct., 1936, pp. 257-274.) (3570 Norway.)

The distribution of velocity and temperature behind a system of parallel equidistant rods is investigated by means of the formulæ of L. Prandtl and G. I. Taylor. The results are checked by measurements taken in the wind channel and in the author's opinion, the agreement is satisfactory.

Two- and Three-Dimensional Motion in Incompressible Fluids Between Eccentrical Cylindrical Surfaces Rotating One Inside the Other. Contribution to the Theory of Lubrication—Part II. (H. Reissner, Z.A.M.M., Vol. 16, No. 5, Oct., 1936, pp. 275-286.) (3571 Germany.)

The author considers the motion between two finite cylinders, postulating that the pressure at the bounding cross-sections is constant. The complete solution is obtained in the form of certain double Fourier series, the coefficients of which are power series of the eccentricity. Experiments confirming the theory are described.

Electrokinetic Processes in Capillary Tubes. (H. Reichardt, Zeitschrift für Physikalische Chemie, Vol. 166, Part 5-6, 1933, pp. 433-452.) (3621 Germany.)

The transfer of an electrolyte through an insulated tube is accompanied by the generation of an electric flow potential already studied by Helmholtz. The electrification is limited to a layer in proximity to the wall, the so-called " double layer," the dimensions of which are small compared with the laminar boundary layer familiar in hydrodynamic problems. Electric forces acting on the double layer may affect the Pouseville velocity distribution and in certain cases may cause an apparent " blocking " of the tube, if the diameter is small enough. The author considers this phenomena in connection with certain osmotic processes in organic cells. (See also page 141, " Electrical Stream Potential during Turbulent Flow.")

On Some Applications of the Theory of Conformal Representation, (B. B. Lavrentieff, Proc. of Joukowsky Academy of Military Aeronautics, No. 13, 1935, pp. 18-27.) (3623 U.S.S.R.)

The theory of conformal representation is applied to wings, the contours which are arcs of circles or inverted parabolas and the conditions for maximum lift are enumerated. The theory is generally analysed and extended in several directions.

The Approximate Integration of the Boundary Layer Equation Using the Theory of Heat Transfer. (L. C. Leybenson, Proc. of Joukowsky Academy of Military Aeronautics, No. 13, 1935, pp. 38-52.) (3624 U.S.S.R.)

The author considers the case of plane surface, a circular or elliptic cylinder and a surface of revolution. For the elliptic cylinder and the surface of revolution, the point of break-away of the flow is also given.

Mechanical and Mathematical Problems Concerning the Improvement of Aerodynamic Efficiency of Wings. (B. B. Goloubeff, Proc. of Joukowsky Academy of Military Aeronautics, No. 13, 1935, pp. 7-17.) (3625 U.S.S.R.)

The theory of slots, slotted ailerons and flaps is briefly considered. Attention is called to the high air speeds existing on the upper surface of the wing near the point of break-away.

Mathematical Problems of the Motion of Gases. (F. Frankl, Proc. of Joukowsky Academy of Military Aeronautics, No. 13, 1935, pp. 28-32.) (3626 U.S.S.R.)

This work deals with the integration of the fundamental differential equation of motion for speeds below and above the velocity of sound (elliptic and hyperbolic partial derivatives). It may be considered as an introduction to the subject and copious references are made to Busemann's papers.

The Theory of the Lifting Surface. (I. Bourago, Proc. of Joukowsky Academy of Military Aeronautics, No. 13, 1935, pp. 53-84.) (3627 U.S.S.R.)

The author considers the 3- dimensional case using vectorial methods and taking into account the possibility of a surface of discontinuity developing in the wake of the body. The theory is extended to the study of the Joukowsky theorem in three dimensions.

AIRCRAFT AND ACCESSORIES.

Charts for Calculating the Performance of Airplanes having Constant Speed Propellers. (R. J. White and V. J. Martin, N.A.C.A. Tech. Note No. 579.) (2898 U.S.A.)

Charts are presented for determining the performance of airplanes having variable pitch propellers so adjusted as to maintain constant speed. The charts

are based on the general performance equation developed by Oswald (N.A.C.A. Tech. Report, No. 408). Examples of applying the charts to airplanes having both supercharged and unsupercharged engines are included.

Tests of a Wing-Nacelle-Propeller Combination at Several Pitch Settings up to 42°. (R. Windler, N.A.C.A. Report No. 564, 1936.) (3586 U.S.A.)

A 4ft. model of Navy propeller No. 4412 was tested in conjunction with an N.A.C.A. cowled nacelle mounted ahead of a thick wing in the 20ft. propeller research tunnel. A range of propeller pitches from 17° to 42° at $0.75R$ was covered, and for this propeller the efficiency reached a maximum at a pitch setting of 27°; at higher pitches the efficiencies were slightly lower. The corrected propulsion efficiency is shown to be independent of the angle of attack for the high-speed and the climbing ranges of flight. A working chart is presented for the selection of similar propellers over a wide range of aeroplane speed, engine power, and propeller revolutions.

Calculations of the Motion of an Airplane Under the Influence of Irregular Disturbances. (Robert T. Jones, J. Aer. Sci., Vol. 3, Oct., 1936, pp. 419-425.) (3520 U.S.A.)

The paper illustrates the application of mathematical advances made in electricity and other branches to problems of aeroplane dynamics. The Heaviside-Bromwich methods of solution of linear differential equations are described and it is shown how these methods avoid the consideration of boundary conditions and of particular or complementary integrals. It is pointed out that the solution of the differential equation is obtained for the case of a unit disturbance, the effect of varying disturbances may be found therefrom by Carson's Theorem. A graphical solution of Carson's Integral for irregular disturbances is given.

The procedure for obtaining unit solutions of the equations is then taken up and the analogy between Heaviside's symbolic series solution and a physical procedure of approximation is shown. It is suggested that a fictitious impulsive disturbance be used in the treatment of initial motions. Bromwich's interpretation of the operational method is briefly described and the expression of the irregular disturbance functions by definite integrals is shown.

An Airfoil Fitted with a Slotted Wing. (G. J. Higgins, J. Aer. Sci., Vol. 3, No. 12, Oct., 1936, pp. 431-433.) (3522 U.S.A.)

The use of the slotted flap on an airfoil has been found to be very advantageous in recent tests conducted in the seven by ten foot wind tunnel of the University of Detroit. A slotted flap of 30 per cent. chord fitted on a Göttingen 398 (modified) airfoil shows a large increase in lift with a very small added drag for small flap deflections. A large reduction in take-off speed with good rates of climb were found obtainable at speeds below the minimum speed for the normal airfoil. Satisfactory air braking is available at high flap deflection. Low relative drag was obtained at zero flap angle by closing the slot entirely in this condition.

Spinning and Tail Buffeting Tendencies and Means by which they can be Detected and Suppressed on a Complete Scale Model in a Wind Tunnel. (W. E. Hunt, J. Aer. Sci., Vol. 3, No. 12, Oct., 1936, pp. 444-447.) (3525 U.S.A.)

The following conclusions are drawn: (1) The vertical position of the horizontal tail surfaces for a low-winged monoplane should be well up on the fuselage, at least 25 per cent. of the root chord above the leading edge of the main wing. (2) By using leading edge slots complete control of the wing root airflow is possible throughout the normal working range of an airfoil, and indications are that they persist some way beyond. (3) Wing root fillets do not by any means

eliminate tail buffeting. (4) The conventional form of horizontal tail surfaces are not as effective, or anywhere near as powerful as the type where the horizontal surfaces move as a whole, and the former greatly aggravate buffeting conditions. (5) The relationship between the main airfoil and horizontal tail surfaces cannot be entirely satisfactory for the low-winged type monoplane and that possibly the best combination would be a high-winged monoplane with the horizontal surfaces well below. (See also Les Ailes, No. 778, 14.5.36, p. 5 and Flugsport, No. 11, 27.5.36, pp. 252-253).

Experimental Researches on the Bending-Torsional Vibrations of a Wing Model of Variable Rigidity. (P. Cicala, Laboretoro de Aeronautica del R. Instituto di Torino, No. 84.) (3636 Italy.)

Wind tunnel measurements of a model wing, 100 × 300 mm. made of Dural plate. The following were investigated: Frequency, type of vibration, phase angle and ratio of amplitudes for different angles of incidence and different ratios of bending to torsional rigidity. (The latter factor remained constant throughout.) The value of the critical air flow is very much reduced for negative angles of incidence. (From 13.5 m./sec. at 7° 25′ to 4.5 m./sec. at −18° 45′.)

This is attributed to the small value of the Reynolds number and the great thickness of the profile under test. (See also H. L. Studer, Proceeding of Institute of Aerodynamics, Zurich, No. 4/5.)

Report on the Progress of Civil Aviation, 1935. (Air Ministry, Department of the Director-General of Civil Aviation.) (3637 Great Britain.)

The appendix of this report (pp. 130-144) contains interesting statistics covering subsidies and miles flown. The following figures applying to five leading countries are of interest. The amount of German subsidy is not given in the report. The figure used has been obtained from German sources.

Country.	Miles Flown.	Subsidy (£).	Miles/£.	£/Passenger.	Passenger/Miles £.
Gt. Britain	8.4×10^6	0.47×10^6	17.8	2.2	90
France	7×10^6	1.33×10^6	5.2	22	15
Holland	3.9×10^6	0.05×10^6	87	0.75	510
Germany	9.3×10^6	1.60×10^6	5.8	9	27
U.S.A.	63.6×10^6	4.11×10^6	15.5	4.8	90

L.Z.—129 Hindenburg by W. V. Langsdorff. (H. Bechild, Frankfurt-Main, 1936 (96 pages).) (3638 Germany.)

This book gives a detailed description of the airship and includes some hitherto unpublished photographs showing various stages of manufacture: Riveting a cross frame, fixing outer cover, suspension of ballast, manufacture of fins, fixing fins and rudder, etc. Sketches show automatic and manœuvring gas valves and details of landing manœuvres and attachment to the mast are given. The following data are of interest:—Weight empty 100 tons. Useful load 30 tons. Oil fuel 60 tons. Ballast 10 tons. Total (at start) 200 tons. The 4 engines develop 4,800 B.H.P. max. and 3,600 B.H.P. cruising. Under these conditions the consumption of fuel is 600 kg./hour and the range is thus 100 hours (at 75 miles/hour) It takes 120 B.H.P. to transport 1 ton of useful load.

The Utilisation of Aerodynamic Research in the Design of Aircraft. (C. B. Millikan, Luftwissen, Vol. 3, No. 10, Oct., 1936, pp. 277-287.) (3639 Germany.)

This paper was read at the annual meeting of the Lilienthal Society in Berlin. The author is professor at the California Institute of Technology where unique facilities for co-operation with industry exist. Amongst the points treated were: (1) Rapid performance calculations for aircraft fitted with constant thrust pro-

pellers. The author is of the opinion that stratosphere flights will be a paying proposition in the near future, provided the range between objectives lies between 1,600 and 2,400 km. (See also page 143, "Charts for Calculating the Performance of Airplanes having Constant Speed Propellers.") (2) Longitudinal stability of low wing monoplanes as affected by position of tail plane. (3) Dynamic criteria for judging performance of civil aircraft. (4) Minimum profile resistance of various aeroplane parts. The author throughout stresses the importance of independent institutions carrying out research for the industry.

ENGINES AND ACCESSORIES.

New German Aero Engine. (Les Ailes, No. 799, 8/10/36, p. 3.) (3101 Germany.)

The firm of Mercedes-Benz have developed a 12 cylinder V engine, 32 litres. The engine is supercharged, ethylene glycol cooled and rated at 1,000 B.H.P. weight 560 kg. This engine is destined for the twin-engined universal fighter and bomber D17, of which several hundred are stated to be in existence. These machines are fitted with 2 cannons and carry 1,000 kg. of bombs. Maximum speed 490 km./hr. According to the French author, the D17 was fitted with K14 (French) engines which will now be replaced by the German (Benz) engines.

Determination of Gas Temperatures during the Expansion Stroke in the Internal Combustion Engine. (Donescu, Chem. Absts., Vol. 30, No. 19, 10/10/36, p. 6919.) (3257 France.)

Methods of measurement and calculation of combustion temperatures are critically reviewed. Calculated values of gas temperatures during and after combustion in an engine may be far from accurate owing to the simplifying assumptions necessarily required. For experimental determination of these values, the Na line reversal method is best. The theory and experimental technique of this method are fully discussed. Data are given for the combustion of C_6H_{11}, iso-octane cyclohexane and C_6H_6, and for an aviation petrol at two compression ratios and two engine speeds.

Kinetic Analysis of the Combustion Phenomenon in the Diesel Engine. (K. Neumann, Chem. Absts., Vol. 30, No. 19, 10/10/36, p. 6921.) (3260 Germany.)

Spectrum studies show that combustion in the engine takes place relatively slowly owing to diffusion in the liquid and solid phases. The velocity of combustion is given by a kinetic equation which depends on the temperature and concentration of the compounds taking part in the reaction. The separation of the reaction-velocity constant into an action constant and activation heat gives an insight into the actual course of the combustion as it is influenced by reaction restraints and reaction accelerators.

The Junkers Diesel Engine. (J. Gasterstädt, Inter. Avia, No. 373/374, 31/10/36, pp. 1-3.) (3406 Germany.)

The first engine (Jumo 204) was put into service in 1932. At the moment Junkers engines average 2,000 flying hours a month. Advance in design whilst scarcely affecting the weight/capacity ratio (55 lb./litre of swept volume) has resulted in a very marked reduction in weight/power ratio (from 2.1 lb./B.H.P. to 1.4 lb./B.H.P.) This is mainly due to improvements in B.H.P./litre output, from 28 for Jumo 204 to 42 for Jumo 206. The 2-stroke Diesel engine, on account of its low exhaust temperature, is specially suited to operating air exhaust turbines. Compensation is possible up to 30,000 feet by means of a special high pressure blower, the turbine delivering 160 B.H.P. for a weight of only 66 lb.

The Pre-Heating of Aero Engines. (E. Dierbach, Z.V.D.I., Vol. 80, No. 43, 24/10/36, pp. 1301-1302.) (3428 Germany.)

The preheater supplies about 1800 cubic feet of free air per minute at 50mm. water pressure and 150° C. The air current is directed over the engine and will raise piston and valve temperature from −20° C. to +30° C. in 15 minutes. This ensures a certain start. The plant described consists of a petrol burner supplied with both primary and secondary air by two centrifugal fans driven electrically. The air supply is sufficient to deal with three engines on an aircraft simultaneously. A considerable number of plants of this type were in use last winter by the German Lufthansa and gave complete satisfaction.

Mixture Distribution in a Single-Row Radial Engine. (H. C. Gerrish and F. Voss, N.A.C.A. Tech. Note No. 583, Oct., 1936.) (3433 U.S.A.)

The distribution of the fuel among the various cylinders of a Pratt and Whitney 1340 SlHl-G engine was determined by chemically analysing samples of exhaust gas from each cylinder. The engine operated in the 20ft. wind tunnel at different power outputs, specific fuel consumptions and engine speeds. The results showed that the variation in the quality of the mixture among the different cylinders was approximately 4 per cent. and was independent of power output, specific fuel consumption and engine speed. The results also showed that the top cylinders operated with a lower air-fuel ratio than the bottom cylinders.

Performance Problems of Aero Engines. (A. Nutt, Luftwissen, Vol. 3, No. 10, Oct., 1936, pp. 287-298.) (3640 Germany.)

This paper was read at the annual meeting of the Lilienthal Society in Berlin. The author is deputy director of design for the Wright Aeronautical Corporation and dealt exclusively with the problems of the air-cooled radial engine. Improvements in the performance of such engines are entirely due to higher operational speeds and increased boost; these are rendered possible by improved cooling (greater fin area), freedom from torsionals (Wright crankthrow vibration damper), better fuels (Octane No. 87), improved spark plugs and better oils. For the latter the absence of rating facilities (corresponding to the C.F.R. method for fuels) is a handicap and the author describes fully a method developed by his firm to overcome this difficulty. (The oil obtains performance marks depending on its behaviour in certain chemical and 50 hr. full-scale engine tests.) In connection with carburation, the icing difficulty can be met in different ways (preheated air or alcohol additions to the fuel). An obvious solution is to design the carburettor in such a way that the ice cannot build up on the throttle (S. P. Johnston, Aviation, Vol. 35, (1936) No. 5, p. 15).

THEORY OF WAR AND ARMAMENTS.

Protection Against Bombing—Design of Suitable Structure. (D. A. Priolo, Riv. Aeron., Vol. 12, No. 5, May, 1936, pp. 183-191.) (1753 Italy.)

Two types of buildings are discussed, depending on whether deflection of the bomb or absorption of the explosion is aimed at. The former is of triangular cross-section with a knife-edge roof, the slope of the walls being such that a bomb striking the building is deflected before explosion. This type can only be erected in isolated positions. In the second type, fitted with a flat roof, intermediate floors are constructed to absorb the kinetic energy of the bomb and direct its path on to the roof of the shelter proper which is placed underground in the basement of the building. This roof is designed to withstand the final explosion. Constructional details are given in sketches.

Toxic Gases. (L. A. Rouget and J. D. Rouget, Chem. Absts., Vol. 30, No. 16, 20/8/36, p. 5681.) (French patent No. 795,793.) (3407 France.)

A chlorinated soap prepared from fat acids of molecular weight below 210 is used to wash clothes which have been subjected to attack by yperite or as a protection on the skin against attack by yperite.

Restraining the Diffusion of Noxious Gases or Vapours. (E. Brezina and W. Schmidt, Chem. Absts., Vol. 30, No. 16, 20/8/36, p. 5681.) (Austrian patent No. 145,523.) (3408 Austria.)

The diffusion of noxious gases or vapours into the air is restrained by maintaining a layer of an innocuous gas over the surface from which the gases or vapours emanate. The innocuous gas is preferably heavier than the air but lighter than the noxious gas or vapour. Cooled air or CO_2 is suitable.

COMBUSTION (FUELS AND LUBRICANTS).

National Fuels and Motor Alcohol. (C. Mariller, Chem. Absts., Vol. 30, No. 17, 10/9/36, pp. 6162-6163.) (3013 U.S.A.)

The use of motor fuels containing alcohol is rapidly spreading in France. Statistical and technical data are given on the various mixtures authorised by law. To augment the fuel supply, the hydrogenation of coal, by a new process, not described, is being introduced in France. The possible use, in Diesel and semi-Diesel engines, of hydrated alcohol or of mixtures of gas oil with 90 per cent. alcohol and a small percentage of *Et* nitrate is discussed.

The Cetene Scale and the Induction Period preceding the Spontaneous Ignition of Diesel Fuels in Bombs. (M. N. Mikhailova and M. B. Neimann, Chem. Absts., Vol. 30, No. 17, 10/9/36, pp. 6176-6177.) (From Comp. Rend., Acad. Sci., U.S.S.R., No. 2, 1936, pp. 143-147.) (3014 U.S.S.R.)

A comparison was made between the cetene scales obtained with mixtures of cetene and l-methylnaphthalene in a bomb and in a C.F.R. engine. The tests were conducted in a metal bomb heated by a nichrome spiral, and the fuel was injected into the bomb from a Bosch jet by means of a specially constructed plunger pump. The diagram from the membrane indicator gave the induction period which corresponds to the time interval between injection and spontaneous ignition. The temperature used was 580°, and this temperature and pressure correspond very closely to those obtaining in a Diesel engine at the end of the compression stroke. Induction periods are reported for mixtures of cetene and l-methylnaphthalene as well as cetene and mesitylene, for a temperature interval of 500-600°. Cetene numbers determined in the C.F.R. engine for eight Diesel fuels are also given. The induction periods of these Diesel fuels were determined by the bomb method and from the values obtained the cetene numbers were taken from the cetene scale. A comparison of the experimentally determined cetene numbers and those determined over the induction periods showed good agreement within the limits of experimental error.

Twelve references.

New Blending Agent Makes Greatly Improved Aviation Fuel. (H. E. Buc and E. E. Aldrin, Chem. Absts., Vol. 30, No. 17, 10/9/36, p. 6177.) (From National Petroleum News, Vol. 28, No. 25, 1936, pp. 25-26 and 28-30.) (3015 U.S.A.)

As shown by tests iso—C_3H_7OH is a satisfactory blending agent, giving an octane number of 105 when blended with 74-octane number gasoline containing not more than 3 cc. of $(C_2H_5)_4$ Pb.

A New Laboratory Method for the Determination of the Volatility of Lubricating Oils for Internal Combustion Engines. (K. Noack, Chem. Absts., Vol. 30, No. 17, 10/9/36, p. 6179.) (From Angew Chem., No. 49, 1936, pp. 385-388.) (3017 U.S.A.)

A review of the following methods is given: Holde drying-oven, Allner, A.S.T.M., I.P.T. (British) and Baader. Their respective advantages and disadvantages are discussed. None of these methods is entirely satisfactory. A new method is described in detail, and the apparatus is shown. The test procedure is as follows: Heat 65 g. of oil for one hour in a brass cup with a screw cap. The heating element is an electrically heated metal block kept at 250°. Insert the brass cup into the metal block immersed in a bath of Wood's metal. Remove the oil vapours formed by means of an air current drawn through three 2 mm. openings in the cap. Adjust the air current to give a suction of 20 mm. of water. Collect the oil distillate, weighing both the distilled oil and the residue. Experimental results are reported for 12 oils varying in viscosity from 4.93° to 12.63° Engler at 50°. Weight losses ranged from 5.8 per cent. (11.55° E.) to 29.7 per cent. (5.93° E.). Repeats are within 0.5 per cent.

Fifteen references.

Motor Fuel (British patent No. 444,026). (E. Bereslavsky, Chem. Absts., Vol. 30, No. 18, 20/9/36, p. 6537.) (3037 Great Britain.)

Motor spirit is obtained by blending gasoline with anhyd. or substantially anhyd. alcohol by means of one or more secondary or tertiary hydroaromatic alcohols of formula $C_{10}H_{16}O$, $C_{10}H_{18}O$ or $C_{10}H_{20}O$, or a substance containing substantial proportions thereof, or a heavy open-chain unsaturated aliphatic primary alcohol of the above formula, or an essential oil containing such alcohol. The blender serves also as an anti-knock agent and as a lubricant and increases the H_2O—tolerance of the fuel.

Unctuosity of Lubricating Mineral Oils. (J. J. Trillat and R. Vaillé, Chem. Absts., Vol. 30, No. 18, 20/9/36, p. 6544.) (From Comp. Rend., Vol. 203, 1936, pp. 159-161.) (3038 France.)

It is shown that oleic acid is adsorbed on filter paper from paraffin oil containing the acid. A content of oleic acid of 1/3,000 was decreased to 1/20,000 by filtration through paper. Filtration through or contact with glass or cotton wool had a similar effect. Other oils containing molecules possessing a permanent electric moment (unsaturated hydrocarbons, aliphatic acids, etc.) behave in the same way. The active molecules are fixed also by metal surfaces.

Boundary Lubrication. (H. Donandt, Chem. Absts., Vol. 30, No. 18, 20/9/36, p. 6544.) (From Z.V.D.I., Vol. 80, No. 27, 4/7/36, pp. 821-824.) (3039 Germany.)

The present knowledge of boundary lubrication is reviewed and results of experiments proved that the friction coefficient of dry friction depends on the nature of the gaseous atmosphere present. It is concluded that four methods exist which increase adsorption in lubrication: (1) Increase the adsorbent power of the oil; this has been done for years, but limits are imposed by the simultaneous increase of the sensitivity to chemical agents, especially O_2. (2) Increase the adsorbent power of the bearing surfaces. (3) Increase the possibility of access of the lubricant to the bearing surfaces by making the latter uneven. (4) Add other substances, *e.g.*, graphite.

Auto-Lubricators (*French patent No.* 796,984). (F. Sattler, Chem. Absts., Vol. 30, No. 18, 20/9/36, p. 6552.) (3042 France.)

An intimate and homogeneous mixture of a metal or metallic alloy powder and powdered graphite is formed, reheated and pressed in successive steps in the same mould and without being withdrawn therefrom between the steps, to form bearings, etc., and these are afterwards tempered.

Contribution to the Theory of Detonation (*Explosives*). (W. Finkelnburg, Z.G.S.S., Vol. 31, No. 4, April, 1936, pp. 109-114.) (3046 Germany.)

Thermo and hydrodynamic considerations (Jouguet, etc.) yield a satisfactory estimate of the velocity of propagation of a detonation wave in a gaseous explosive. Such investigations, however, throw no light on the mechanism of the reaction. The author points out that in the front of the detonating wave the constituent molecules and atoms possess velocities which are the sum of those due to thermal agitation (temperature) and gas velocity proper (rate of transfer). In this way he accounts for some of the experiments of Muraour and Michel-Levy (gas glow).

Problems of Ignition and Flame Propagation. (W. Jost, Chem. Absts., Vol. 30, No. 19, 10/10/36, p. 6919.) (3255 Germany.)

It appears that the flame is propagated by the projection of activated particles as well as by conduction. The initiation of the combustion by means of a spark may introduce free radicles and atoms and these may play a part in the subsequent reaction. The presence of free ions in the flames is also discussed. It appears that considerably more experimental work is required to clarify the whole process.

The Mechanism of the Combustion of Hydrocarbons. (A. R. Ubbelohde, Chem. Absts., Vol. 30, No. 19, 10/10/36, p. 6920.) (3258 Germany.)

With paraffins containing more that 3-4 C. atoms there occurs, on ignition, reaction in the "low temperature region" (250°-320°) with characteristic chemiluminescence, vigorous dependence of the ignition temperature on composition and pressure, high sensitivity toward positive and negative catalysts such as anti-knock agents, and formation of peroxides in quantities that can be isolated. The knocking tendency in engines is related to this combustion in the low temperature area.

The Combustion Process in the Explosion Motor. (A. von Phillippovich, Chem. Absts., Vol. 30, No. 19, 10/10/36, pp. 6920-6921.) (3259 Germany.)

Various factors affecting the combustion process in the engine are studied both for the carburettor and the injection engine (compression ratio, boost, ignition, r.p.m., mixture temperature, cylinder temperature). Most of the work was done on C.F.R. cylinders. The onset of detonation was recorded by a piezo-electric indicator. The resistance to detonation cannot as yet be predicted by purely chemical means.

Some Influences of Dilution on the Explosive Combustion of Hydrocarbons. (W. A. Bone and L. E. Outridge, Proc. Roy. Soc., Vol. 157, No. 891, 2/11/36, pp. 234-248.) (3363 Great Britain.)

The paper deals with certain effects of dilution with inert gases (Ar, He, and N_2) upon explosions of equimolecular mixtures of ethylene or acetylene and oxygen, *i.e.*, $C_2H_4+O_2$ and $C_2H_2+O_2$ which normally give rise to carbonic oxide and hydrogen without any separation of carbon or steam formation. It is now

shown by chemical, photographic, and spectographic tests that sufficient dilution of such media, while not much affecting the main result, may induce some secondary carbon deposition and steam formation on explosion when the mean flame temperature is thereby reduced to a point well below 2,000°C., such result being probably due to the fall in flame temperature induced by dilution.

Combustible Gas Mixture (British patent No. 446,493). (Chem. Absts., Vol. 30, No. 20, 20/10/36, p. 7314.) (3379 Germany.)

The object is to obtain gas mixtures which can be liquefied at normal temperature and relatively moderate pressures (20-30 atmospheres). The main source of supply is coke oven gas and it is shown that the liquefying pressure required is mainly determined by the C_2H_6 and C_2H_4 content. If this is kept low (12.5 per cent.), the pressure needed is reduced to 18 atmospheres, whilst the presence of 35 per cent. C_2H_6 and C_2H_4 requires 30 atmospheres. Abstractor's Note.—Considerable attention is given to the use of compressed fuel gases on motor lorries in Germany at the present time.

Apparatus for Analysis of Gases such as Automobile Engine Exhaust Gases. (L. L. Vayda, Chem. Absts., Vol. 30, No. 20, 20/10/36, p. 7315.) (U.S. patent No. 2,053,121.) (3380 U.S.A.)

Unlike other well known forms of exhaust gas analysers which depend on the heat conductivity of the gas varying with its composition, the present apparatus utilises catalytic combustion to indicate how far chemical equilibrium has been established. Various structural and operative details are given.

Correlation of Tests on the Ignition Quality of Diesel Fuels carried out at Delft and Sunbury. (G. D. Boerlage and others, Chem. Absts., Vol. 30, No. 20, 20/10/36, p. 7317.) (3381 Great Britain.)

Co-operative tests of the ignition quality of Diesel fuel by the laboratory of the Royal Dutch Shell, at Delft, Holland, and that of the Anglo-Persian Oil Co., at Sunbury, showed satisfactory agreement in general, notwithstanding that eight different engines were employed. Vegetable oils and doped fuels have to be tested in the engine in which they are to be used. The proper determination of cetene number is not likely to be as exacting as that of octane number. A variation of a few points in the cetene number is not significant, especially in the upper ranges.

Surface Films and Lubrication. (D. R. Pye, J.R. Aer. Soc., Vol. 40, No. 310, October, 1936, pp. 754-768.) (3416 Great Britain.)

Friction and metallic cohesion are in the first phase essentially similar. Viscosity is important in a lubricant because between uneven surfaces the time taken to squeeze away a more viscous oil (and establish the dangerous state of boundary lubrication between two high spots) is greater than with a less viscous oil. A powerful primary film is a safeguard against seizure and depends on the presence of polar molecules together with a receptive bearing surface. It is necessary for the polarity to persist up to relatively high temperatures and oil stability is thus of importance. If after all break down occurs, the effects of the resultant seizure can be minimised by the preparation of the solid surface in such a form as to resist mutual cohesion of the molecules across the interface at the moments of breakdown of the primary film. The well known good surface qualities of cast iron are due to the presence of free graphite and in that case of other metals, similar beneficial results may result from polishing and other forms of surface treatment. (See also Abstract No. 3039 Germany.)

Pro-Knocks and Hydrocarbon Combustion. (A. R. Ubbelohde and others, Proc. Roy. Soc., Vol. 153, No. 878, 2/12/35, pp. 103-115.) (3418 Great Britain.)

In a previous paper (Phil. Trans. Roy. Soc., Vol. 234, 1935, p. 433) the authors showed that knocking in an internal combustion engine is associated with the presence of peroxide substances formed in the last part of the charge to burn. In the present paper, the authors describe further experiments with the sampling valve from which it appears that the knocking is not due to the formation of aldehyde peroxide, but that direct peroxidation of the fuel is responsible. It was also established that no NO_2 is formed during the compression stroke and that the presence of this gas is most likely due to the catalytic effect of the metal exhaust valve during the combustion stroke.

Sewer Gas for Internal Combustion Engines. (W. Ryssel, Z.V.D.I., Vol. 80, No. 43, 24/10/36, p. 1290.) (3426 Germany.)

Sewer gas is obtained in the settling tanks of the sewage farm and has the following approximate composition :—

75 per cent. methane
22 per cent. CO_2
2.7 per cent. N_2
0.2 per cent. H_2
0.1 per cent. H_2S

Its upper calorific value is approximately 7,200 *k* cal./m.^{3}. In Stuttgart (Germany) approximately 36 lorries are operated by the gas, supplied at 200 atmospheres in steel bottles. Experience has shown that 1 m.^{3} of the unpurified gas is approximately equivalent to 1 litre of petrol, the compression ratio of the engine being unaltered. There is a power drop of approximately 10 per cent. compared to petrol. The operation with sewer gas (practically methane) is characterised as very smooth. Engines remain very clean and there is no dilution of the lubricating oil. (See also Abstract No. 3379 Germany.)

Experiments with Bearings with High Pressure Lubrication. (G. Welter and W. Brasch, Phys. Berichte, Vol. 17, No. 20, 15/10/36, p. 1849.) (3446 Germany.)

Before starting the engine, the bearings are supplied with oil at sufficiently high pressure to ensure that the shaft is lifted off the bearing shell. The starting friction is thus reduced below the normal operating value and wear becomes negligible.

Coal Gas as a Fuel for Motor Car Engines. (W. Rixmann, Z.V.D.I., Vol. 80, No. 21, 23/5/36, pp. 627-632.) (3598 Germany.)

Bench tests were carried out on a six-cylinder 10.85 litre engine developing approximately 100 b.h.p. on petrol (1,400 r.p.m.). With the compression ratio unchanged (*CR* = 5.05) coal gas gave 12 per cent. less power. By raising the *CR* to 7.5 (preignition limit), this was reduced to 2 per cent. The relatively small drop in power with gas is explained by the higher volumetric efficiency of the engine in this case (80 per cent. with gas against 66 per cent. petrol). Best consumption figures are approximately 0.75 cubic metre of gas per b.h.p. hour against 260 gm. of petrol. The former was obtained at *CR* 7.5 (lower calorific value 3,420 *k* cal./m.^{3}), the latter at *CR* 5.05 (lower calorific value 9,800 *k* cal./kg.). It will be seen that the thermal efficiency is the same in spite of the difference in *CR*. Considerable difficulty is experienced to devise an automatic gas carburettor. Various designs using quantity or quality governing are described and a combination of the two methods is recommended. A considerable number of heavy vehicles using compressed coal gas are in operation in Germany. (See also Abstracts Nos. 3379 Germany and 3426 Germany.)

MATERIALS AND ELASTICITY.

Charts for Checking the Stability of Compression Members in Trusses. (K. Borkmann, N.A.C.A. Tech. Memo. No. 800, translated from L.F.F., Vol. 13, No. 1, 20/1/36, pp. 1-9.) (754/2909 Germany.)

In practice the more general method of checking the stability of trusses (as of fuselage or wing spars) has been to take the effect of fixity into account, by using fixity factors. This may lead to error, since the fixity does not only depend on the truss design but also on the stress existing in the whole system. A more accurate method is the following:—The buckling strength of a truss within a system with spatially defined nodal points is determined by resolving the entire truss into groups of members, each group being assumed rigid, but the individual groups hinged. The buckling criterion then follows from a determinant equation which is rather complicated. The charts presented in the present paper are based on the same formulæ, but reduce the amount of paper work considerably.

Viscosity of Liquid Sodium and Potassium. (Y. S. Chiong, Proc. Roy. Soc., Vol. 157, No. 891, 2/11/36, pp. 264-277.) (3365 Great Britain.)

The viscosity of liquid sodium and potassium has been measured by the oscillating sphere method, in which the liquid is enclosed in a glass sphere, and its viscosity calculated from the damping of the oscillation. The alkali metals have been chosen because their simple crystal structure has advantages for comparison with theory. The measurement was done from the immediate neighbourhood of the melting point up to about 360°C. Results obtained for both sodium and potassium are found to obey satisfactorily the two viscosity formulæ of Andrade.

Note on Fracture. (H. Jeffreys, Proc. Roy. Soc. of Edinburgh, Vol. 56, Part 2, 1936, pp. 158-163.) (3532 Great Britain.)

The usual Coulomb-Hopkins theory of fracture asserts that fracture begins at the time and place where the difference between the greatest and least of the principal stresses first reaches the strength of the material. On the more recent theory of Mieses, the stress difference is not the only determinant, but the function whose value determines whether fracture occurs or not is so nearly proportional to the square of the stress difference, that very special experimental conditions are needed to find out which criterion is the better. The form of the fracture surface is determined by change of stress arising during fractures and not by the original distribution of stress.

On the Boundary Problem of the Uniformly Loaded Circular Plate. (J. Barta, Z.A.M.M., Vol. 16, No. 5, Oct., 1936, pp. 311-314.) (3572 Austria.)

If the deflection and its normal derivative at the edge of the plate are given functions, then the deflection at an interior point may be calculated as the mean value of the deflections of all chords passing through this point, each chord being regarded as a uniformly loaded beam with corresponding deflections and derivatives at the ends.

The Transmutation of Matter by High Energy Particles and Radiations. (The 27th Kelvin Lecture.) (J. D. Cockroft, J. Inst. Elec. Eng., Vol. 79, No. 479, Nov., 1936, pp. 532-540.) (3593 Great Britain.)

One ounce of matter, completely transformed, would produce 700 million kilo. watt hours of energy. Laboratory transmutation is, however, hopelessly inefficient. The problem would come into the realm of possibility, if streams of neutrons could be employed, for such particles lose no energy to electrons and the efficiency in producing transmutations may approach 100 per cent. Unfortunately, at the present time, the neutrons themselves can only be produced by

the interaction of charged nuclei at a very low efficiency. It is of interest to note that at stellar temperature a conversion of mass into energy takes place on a large scale. It is this process which maintains solar temperature and accounts for the synthesis of the elements.

A Record of Recent Progress towards Correlation of the Chemical Composition, the Physical Constitution and the Electrical Properties of Solid Dielectric Materials. (W. Jackson, J. Inst. Elec. Eng., Vol. 79, No. 479, Nov., 1936, pp. 565-576.) (3594 Great Britain.)

The chemical and physical complexity of most of the solid dielectric materials which find application in electrical engineering practice makes an understanding of their electrical behaviour an extremely difficult matter, since the phenomena underlying conduction processes even in simple solid materials are not fully understood. A considerable amount of work has been carried out during recent years in an endeavour to clarify this behaviour, and in consequence there has been a very noticeable tendency to develop new materials on a scientific basis. The present paper is an attempt to gather together in summarised form the published information relating to this work and is an extension of a previous résumé covering liquids.

Spot-Welding and Forging of Steel. (Military Air Academy of the Red Worker and Peasants' Army, Proceedings No. 12, 1935.) (3622 U.S.S.R.)

Spot-Welding, pp. 5-68:—The factors controlling spot-welding depend on the composition of the steel. Control should be specially rigid in the case of V2A steels, whilst chrome-molybdenum steels show greater latitude. *Forging*, pp. 71-230:—The toughness, plasticity and fatigue limits of E18 steel are correlated to the degree of forging of the material. The lack of uniformity of the products of certain steelworks is pointed out and remedies are indicated. By keeping a log of the practical performance of the finished article (crankshaft) together with the source of origin, it is hoped that manufacturers will obtain the necessary incentive.

Transfer of Stress from Main Beams to Intermediate Stiffeners in Metal Sheet Covered Box Beams. (B. B. C. Lovett, J. Aer. Sci., Vol. 3, No. 12, Oct., 1936, pp. 426-430.) (3521 U.S.A.)

The authors have obtained by experimental methods an effective shear modulus for the sheet in a stiffened plane sheet beam combination under bending loads. For the combinations tested it was found that the modulus decreases rapidly under light loadings from the elastic value to some asymptotic value depending upon the sheet thickness. The thick sheet combination gave higher values of the effective shear modulus than the thin sheet.

Effect of Rivet Spacing on Stiffened Thin Sheet Under Compression. (W. L. Howland, J. Aer. Sci., Vol. 3, No. 12, Oct., 1936, pp. 434-439.) (3523 U.S.A.)

It had previously been found that for the same spacing between attachments, a sheet stiffener combination will carry most load if welded and least if bolted. Riveting is intermediate. The present paper investigates the effect of size and position of rivets. The conclusions are that the spacing of the rivets should not be too close and the rivets as large as possible.

A Method of Stress Analysis of Monocoque Fuselage Circular Rings. (E. J. A. Greenwood, J. Aer. Sci., Vol. 3, No. 12, Oct., 1936, pp. 440-443.) (3524 U.S.A.)

The purpose of this paper is to outline a method which may be used for the determination of the forces in a monocoque fuselage circular ring which is sub-

jected to concentrated external forces and moments. The balancing forces are considered to be applied by the fuselage skin, which is the usual design condition. Coefficients for determining the bending moment, shear, and axial load at any point in a ring have been derived and a method of plotting these in terms of the applied load and radius of curvature of the ring is presented. By use of these curves the stress at any ring section may be readily determined for the loading condition considered in this paper. Curves similar to those presented here may be constructed for other basic loading conditions.

METEOROLOGY AND PHYSIOLOGY.

Airplane Tracks in the Surface of Stratus Clouds. (Irving Langmuir and Alexander Forbes, J. Aer. Sci., Vol. 3, No. 11, Sept., 1936, pages 385-387.) (3515 U.S.A.)

Cloud-forms differ in stability according to their type. Cumulus clouds are characterised by turbulence, whereas stratus clouds are, by contrast, stable and relatively static. The authors describe a series of observations in which the stability of stratus clouds was shown by the persistence of tracks made in them by aeroplanes. The authors consider that the track is caused by the weight of the aeroplane giving to the air along the track a downward component of velocity which results in the warm, dry air, just above the cloud, being forced down into the cloud. Attempts were made to cut visible tracks through the tops of rounded cumulus clouds but the tracks were indistinct and quickly disappeared, agreeing with other evidence of turbulence in cumulus clouds. The authors conclude from a comparison of observations made that a sharply defined upper surface of a stratus cloud, correlated with inversion of temperature, presents a condition of great stability, and that in the case of stratus clouds the more sharply defined the surface, the greater is the stability. (Photographs of tracks are shown.)

Change of Boiling Point of Liquid Oxygen at High Altitudes. (Jean Piccard, J. Aer. Sci., Vol. 3, No. 11, Sept., 1936, page 406.) (3519 U.S.A.)

When an aeroplane is rising, the boiling point of liquid oxygen is constantly diminishing. The liquid is therefore boiling more violently and is cooling far below its normal boiling point. When the ceiling is reached and the pilot commences his return voyage to earth, the atmospheric pressure on his oxygen apparatus immediately begins to rise and the liquid stops boiling, with the result that gas production stops entirely, and, in addition, the cold liquid begins to condense nitrogen and oxygen at its surface. In this manner, air is even sucked back from the gas mask into the bottle. The author describes his experience with this phenomenon and points out the danger to aviators engaged in high altitude flights when a gas mask employing liquid oxygen is used. There is very real danger of suffocation on the descent to earth.

MISCELLANEOUS.

French Aerodynamic Research Institution's Exhibit at the Paris Show. (Les Ailes, No. 805, 19/11/36, p. 5.) (3618 France.)

Amongst items of interest are:—(1) Study of flow round propellers and wings by means of smoke jets, the flow being examined stroboscopically. (2) Boundary layer control by moving belt forming part of wing surface. (3) Dropping tests to study effect of high Reynolds numbers on resistance. The buoyant model is dropped into a lake and the retardation recorded. (4) Gunpowder engine by Riabouchinsky. Powder cartridges are fired in succession and the resultant gas operates a reaction turbine geared to a propeller. (5) Supersonic wind tunnels of the induced flow type (injector). (6) Hydrodynamic analogy of supersonic flow by study of surface waves and ripples in liquids.

SOUND, LIGHT AND HEAT.

The Modulation of a Light Source by Means of Supersonic Waves. (H. E. R. Becker, H.F. Technik., Vol. 48, No. 3, Sept., 1936, pp. 89-91.) (3048 Germany.)

The sound waves are generated piezo-electrically inside a liquid in a tank, the energy required being very small (less than 0.1w). The method depends on the Debye-Sears phenomenon of diffraction and has possible application to television.

Heat Conductivity of Gases with Free Convection. (W. Weizsäcker, Phys. Zeit., Vol. 37, No. 18, 15/9/36, pp. 641-650.) (3179 Germany.)

The free convection in an enclosure is reduced as the gas pressure is reduced and disappears at a certain critical pressure which is a characteristic of the gas examined. For hydrogen true conduction is set up at absolute pressures of the order of 80 mm. of mercury. For CO_2 and air much lower pressures are required (10-20 mm.)

A Study of the Characteristics of Noise. (V. D. Landon, Proc. Inst. Rad. Eng., Vol. 24, No. 11, Nov., 1936, pp. 1514-1521.) (3488 U.S.A.)

It is well known that when smooth noise such as hiss is passed through or generated in a radio-frequency amplifier, the root-mean-square output is proportional to the square root of the frequency band width. Experiments are described which show that the peak value of the hiss is also proportional to the square root of band width. The crest factor (defined as the ratio of the amplitudes of the highest peaks to the root-mean-square value) was found to be equal to 3.4 and independent of band width. When the noise is caused by impulse excitation with decay trains not overlapping, the result is quite different. The root-mean-square amplitude is still proportional to the square root of frequency band passed; however, the peak amplitudes are directly proportional to the first power of the frequency band. The result is verified mathematically and experimentally.

ELECTRICITY.

Ultra-High-Frequency Transmission between the R.C.A. Building and the Empire State Building in New York City. (P. S. Carter and G. S. Wickizer, Proc. Inst. Rad. Eng., Vol. 24, No. 8, Aug., 1936, pp. 1082-1094.) (2465 U.S.A.)

Propagation between these two buildings at a frequency of 177 megacycles has been studied with the object of providing a radio circuit with flat response over three megacycles. It was found that the received signal arrived over several paths, some of which were due to reflections from ground and from nearby buildings. The effects on the indirect rays of horizontal and vertical directivity, and change in angle of polarization were observed. The theoretical response curve for an assumed combination of rays was compared with the curves obtained experimentally.

Electron Optical System of Two Cylinders as Applied to Cathode-Ray Tubes. (D. W. Epstein, Proc. Inst. Rad. Eng., Vol. 24, No. 8, Aug., 1936, pp. 1095-1139.) (2466 U.S.A.)

The electron beam of a cathode-ray tube is usually focussed by means of an electron optical system of two coaxial cylinders. This paper presents a detailed treatment of such a focussing system and is divided into two parts. Geometric electron optics of axially symmetric electrostatic fields is presented in Part I.

This deals with (1) the analogy between light and electron optics, (2) motion of electrons in axially symmetric electrostatic fields, (3) definition and determination of positions of cardinal points due to axially symmetric electrostatic fields, and (4) thick and thin lenses. The lenses equivalent to the electrostatic fields of two coaxial cylinders are discussed in Part II.

This deals with (1) positions of cardinal points due to two coaxial cylinders of various diameters and at various voltages, (2) use of such cardinal points, (3) experimental determination of positions of cardinal points, and (4) spherical aberration of electrostatic field due to two cylinders. The results are applied to the cathode-ray tube.

Magnetron Oscillators for the Generation of Frequencies between 300 and 600 Megacycles. (G. R. Kilgore, Proc. Inst. Rad. Eng., Vol. 24, No. 8, Aug., 1936, pp. 1140-1157.) (2467 U.S.A.)

The need for vacuum tube generators capable of delivering appreciable power at frequencies from 300 to 600 megacycles is pointed out and the negative resistance magnetron is suggested as one of the more promising generators for this purpose. An explanation of the negative resistance characteristic in a split-anode magnetron is given by means of a special tube which makes possible the visual study of electron paths. In this manner it is demonstrated how most of the electrons starting toward the higher potential plate reach the lower potential plate. From the static characteristics it is shown how the output, efficiency, and load resistance can be calculated. Two methods are described for increasing the plate-dissipation limit. One method is that of increasing the effective heat-dissipating area by the use of an internal circuit of heavy conductors. The other method is that of a special water-cooling arrangement which also makes use of the internal circuit construction. Examples of laboratory tubes are illustrated, including a radiation-cooled tube which will deliver 50 watts at 550 megacycles and a water-cooled tube which will deliver 100 watts at 600 megacycles.

Beam Wireless Direction Finding Using Two Similar and Separately Tuned Receiving Antennæ. (Telefunken, German patent No. 628,763.) (H.F. Technik, Vol. 48, No. 3, Sept., 1936, p. 109.) (3050 Germany.)

In the case of the Adcock direction finder (freedom from night effects) the tuning of the two receiving antennæ is difficult. In the present patent tuning is achieved by utilising an auxiliary transmitter which is placed symmetrically with the antennæ and which is in tune with the beam. Correct tuning of the antennæ is checked by putting them in opposition when the E.M.F. generated should cancel out.

The Propagation of Radio Waves Over the Surface of the Earth and in the Atmosphere. (K. A. Norton, Proc. Inst. Rad. Eng., Vol. 24, No. 10, Oct., 1936, pp. 1367-1387.) (3361 U.S.A.)

Simple formulæ and graphs are given which represent the ground-wave field intensity at the surface of the earth as radiated from a short vertical antenna at the surface of the earth. The theory is compared with some experimental results reported by other investigators. The diffraction formula given is theoretically valid only at the lower frequencies; however, it was shown that sky waves are important both day and night and over land and sea at those distances where diffraction would otherwise cause a marked decrease in the received field intensity. The attenuation formula given for the short distances where diffraction may be neglected is theoretically valid for any frequency and set of ground constants; experimental data are given which show that the formula may be used at the ultra-high frequencies.

Modified Sommerfeld's Integral and its Application. (S. A. Schelkunoff, Proc. Inst. Rad. Eng., Vol. 24, No. 10, Oct., 1936, pp. 1388-1398.) (3302 U.S.A.)

The purpose of this paper is to obtain a certain integral expressing fundamental wave function and with the aid of this integral to calculate the radiation resistance of small doublets and small loops placed inside an infinite hollow cylinder. Some applications of this integral to calculation of radiation from parallel wires in free space are also discussed.

The Experimental Determination of the Velocity of Radio Waves. (R. C. Colwell and others, J. Frank. Inst., Vol. 222, No. 5, Nov., 1936, pp. 551-552.) (3559 U.S.A.)

A radio station "A" sends out sixty short pulses a second; another station " B " at a distance of twenty kilometres is also sending out sixty pulses per second. By means of a phase shifter, the operator at " B " can send his pulses back to "A" at the exact instant of reception. Hence the station " B " acts as a reflector for the pulses. The operator at " B " sets his pulses in coincidence with those from "A" with the aid of an oscilloscope having a sixty cycle sweep. The operator at "A" measures the distance between the two groups of pulses seen on the oscilloscope. Since the sweep rate of the oscilloscope is known, the velocity can be calculated. For the medium-high frequency waves used, the velocity is considerably less than the velocity of light, varying from $\frac{1}{2}$ to $2/3$ of that constant depending on meteorological conditions. The reduction appears to be largely due to conductivity and variation in the dielectric constant of the earth.

Television Exhibit at the Brussels International Exhibition. (R. Barthélemy, Revue Générale de L'Électricité, Vol. 38, No. 12, 21/9/36, pp. 405-410.) (3569 Belgium.)

Visitors were moved past the exhibit by a slowly moving platform and in this way large numbers could be dealt with. The apparatus, of French design, and similar to that installed at the Eiffel Tower, utilises a spiral Nipkow disc and a 60 line Cathode Ray picture. The definition is improved by giving each line a small oscillatory motion. In this way, the dark horizontal intervening spaces disappear and the impression of a 120 line scanning is given. The special synchronising device (short signal at end of each line) and its associated thyratron circuit is described.

REVIEWS.

Home Grown Timbers.

Department of Scientific and Industrial Research. H.M.S.O. 1936. 1s. 6d.

Wood will continue to be used in aircraft construction for many years, despite the great advances which are being made in light alloys. There is a tendency for the student to neglect wood and its properties, but he will always find that a sound knowledge of timber will prove invaluable. He should have the knowledge of all materials of construction, for specialisation on any given material leads to a narrow outlook which invariably leads to a certain amount of cramping in design. Most engineering structures call for a use of a number of materials and the good designer is one who has the varied knowledge which enables him to choose the best material for the particular work or part of it.

A handbook of Home Grown Timbers is a sequel to the Uses of Home Grown Timbers published in 1927, and contains the results of recent investigations carried out at the Forest Products Research Laboratory. These investigations cover the general description of each home grown timber, its seasoning properties, mechanical properties, durability, freedom from insect attack, working qualities and uses. Woods like ash, spruce and walnut are well known to designers, but there are many described in the book which would be of use, for parts that are not stressed, for their durability and ornamentation.

The Air Annual of the British Empire, 1937.

Published by Sir Isaac Pitman & Sons, Ltd. Price 21/-.

The literature of the air is assuming such great proportions that more and more for the general reader, it is necessary to have books of reference which cover a wide field. Among such books none is more welcome than the Air Annual of the British Empire, now in its 8th year. Published a little later on in the year than usual this was entirely in order, that in view of the great expansion now taking place, the Annual should be as nearly up to date as possible. Its illustrations are indicative of the fact that the Editor, Squadron Leader C. G. Burge, has once more succeeded in his task. Here we see the Vickers Supermarine Spitfire, the Fairey Battle, the Vickers Wellington I, the Bristol Type 142, and many others, on the military side, and the Short Empire Flying Boat, the Jumping Autogiro and the Percival Vega Gull among Civil aircraft.

The Annual is a mass of information not only about aircraft on the military and civil side but of British air lines and the development of civil aviation in the British Empire in all its aspects. Here too, is a summary of all those things which go to make British aircraft among the finest in the world, its materials and accessories.

As usual there are a number of important articles showing the technical developments during the previous year, notably " British Aircraft Developments During 1936," by S. Scott Hall, " Recent Aerodynamic Improvements in the Aeroplane," by H. B. Irving and " Pioneer Work in the Fleet Air Arm," by Flying Officer W. H. Dunton.

The Annual contains many tables and full descriptions of British aircraft, which cannot help but be of the greatest possible use to all who are interested in aviation. It is interesting, too, to note that the author has persuaded Mr. J. E.

Hodgson to write a short article on " The Centenary of the First Long-Distance Oversea Voyage by Air." This was by Green, Holland and Monck Mason on November 7th, 1836, when the three flew from Vauxhall Gardens and after a voyage through the night, landed not far from Weilberg in the Duchy of Nassau. They had covered a distance of about 450 miles from London in 18 hours. It is interesting to note that in connection with this voyage there was issued the first aviation passport, now in the possession of the Royal Aeronautical Society.

The Air Annual of the British Empire is indispensable and its eight volumes form a co-ordinated review of the progress of British aviation during the past eight years which is not to be found anywhere else.